CHAPTER III - SUMMARY OF TROPICAL CYCLONES

1. WESTERN NORTH PACIFIC TROPICAL CYCLONES

During 1984, the western North Pacific experienced the sixth consecutive year of below average tropical cyclone activity. Thirty tropical cyclones occurred in 1984, one less than the annual average. Only three significant tropical cyclones failed to develop beyond the tropical depression (TD) stage and eleven tropical storms (TS) failed to reach typhoon intensity. Of the 16 tropical cyclones that developed to typhoon (TY) intensity, two reached the 130 kt (67 m/s) intensity necessary to be classified as super typhoons (STY). In the western North Pacific, tropical cyclones reaching tropical storm intensity or greater are assigned names in alphabetical order

from a list of alternating male/female names (refer to Appendix III). Table 3-1 provides a summary of key statistics for all western North Pacific tropical cyclones. Each tropical cyclone's maximum surface wind (in knots) and minimum sea level pressure (in millibars) were obtained from best estimates based on all available data. The distance traveled (in nautical miles) was calculated from the JTWC official best tracks (see Annex A).

Table 3-2 through 3-5 provide further information on the monthly and yearly distribution of tropical cyclones and statistics on Tropical Cyclone Formation Alerts and Warnings.

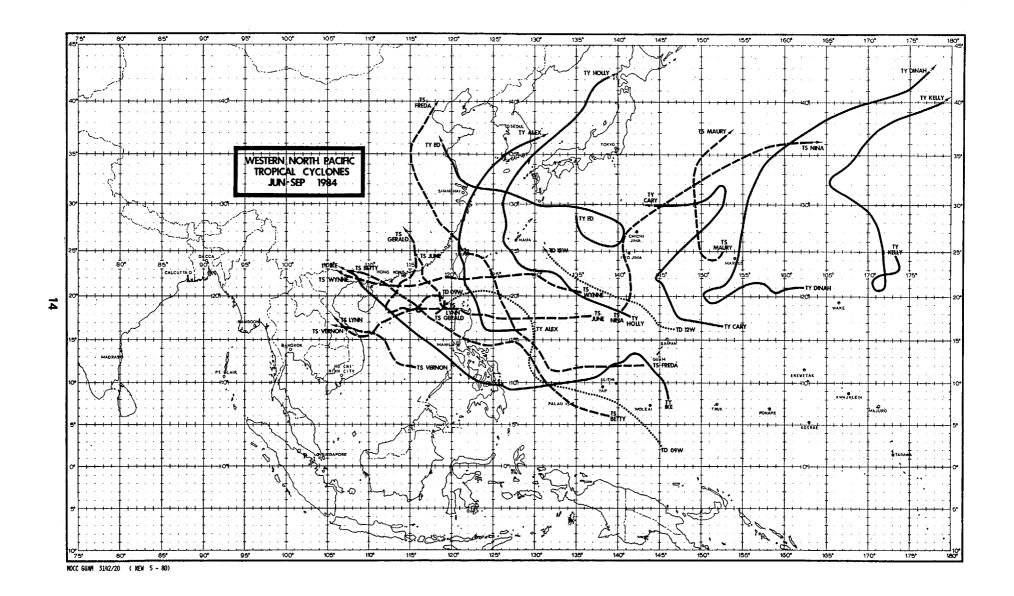
TABLE 3-1.		и	ESTERN NO	RTH PACIFIC					
		1984 SIGN	HIFICANT	TROPICAL	CYCLONES				
TROPICAL C	YCLONE	PERIOD OF WARNING	CALENDAR DAYS OF WARNING	NUMBER OF WARNINGS ISSUED	MAXIMUM SURFACE WINDS (KT)	ESTIMATED MSLP (MB)	BEST TRACK DISTANCE TRAVELED (NM)		
02W TS WY 03W TY AI 04W TS BI 05W TY C	ERNON YNNE LEX ETTY ARY INAH	09 JUN - 11 JUN 19 JUN - 26 JUN 01 JUL - 05 JUL 06 JUL - 09 JUL 07 JUL - 14 JUL 24 JUL - 01 AUG	3 8 5 4 8 9	9 28 18 12 30 35	40 60 75 55 90 125	993 980 970 983 955 915	556 1609 1320 1157 1355 2826		
10W TS GE 11W TY HO 12W TD 12	REDA 9W ERALD OLLY 2W	25 JUL - 01 AUG 05 AUG - 08 AUG 11 AUG - 15 AUG 16 AUG - 21 AUG 16 AUG - 22 AUG 24 AUG - 25 AUG	8 4 5 6 7 2	28 12 10 24 25 5	100 55 30 55 75 20	947 982 996 979 963 995	1700 1894 1328 1009 1712 605		
14W TS JU 15W TY KE 16W TS LA 17W TS M	YNN	27 AUG - 06 SEP 28 AUG - 30 AUG 13 SEP - 18 SEP 24 SEP - 27 SEP 28 SEP - 01 OCT 28 SEP - 01 OCT	11 3 6 4 4	42 11 18 14 13 15	125 60 75 40 60 55	947 983 965 996 992 990	2806 738 1297 553 863 1201		
21W TS RC 22W TS SU 23W TD 23	HYLLIS OY USAN	07 OCT - 10 OCT 11 OCT - 14 OCT 11 OCT - 13 OCT 11 OCT - 12 OCT 17 OCT - 18 OCT 19 OCT - 24 OCT	4 4 3 2 2 6	12 13 9 5 4 21	70 80 35 40 25 120	982 974 996 992 998 925	1236 972 735 576 287 2362		
25W STY VI 26W TY WZ 27W TY AC 28W STY BI 29W TY CI 30W TY DO	ENES ILL LARA		10 9 8 15 8	31 31 28 52 30 26	155 65 120 130 110 125	979 976 925 909 938 935	3125 1111 2666 2892 2709 1960		
1984 TOTALS: 130* 611 * OVERLAPPING DAYS INCLUDED ONLY ONCE IN SUM.									

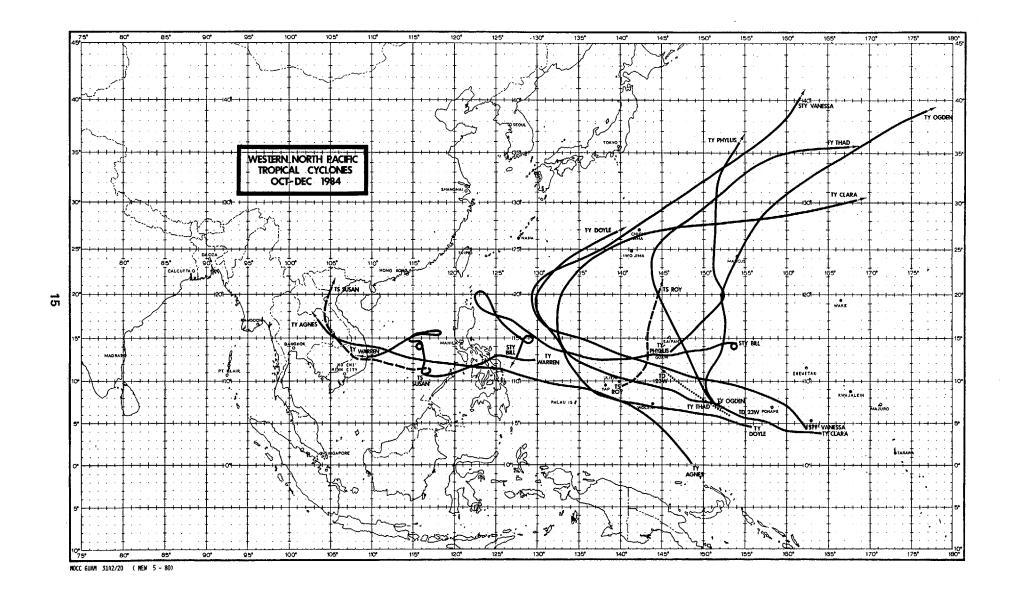
TABLE 3-2.															
WESTERN			19	84 SI	GNIFI	CANT	TROPI	CAL C	YCLON	ES					
NORTH PACIFIC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	<u>oct</u>	NOV	DEC	TOTAL	(1959-1 AVERAGE	.984) CASES
TROPICAL DEPRESSIONS	0	0	0	0	0	0	0	2	0	1	0	0	3	3.8	98
TROPICAL STORMS	0	0	0	0	0	2	1	3	3	2	0	0	11	10.0	259
TYPHOONS	0	0	0	0	0	0	4	2	1	5	3	1	16	17.3	451
ALL TROPICAL CYCLONES	0	0	0	0	0	2	5	7	4	8	3	1	30	31.1	808
1959-1984 AVERAGE	.5	.3	.7	.8	1.3	2.0	4.9	6.3	5.7	4.6	2.7	1.4	31.1		
CASES	13	8	18	22	33	51	127	163	148	119	70	36	808		
FORMATION ALERTS: 30 of 37 Formation Alerts developed into significant tropical cyclones. Tropical Cyclone Formation Alerts were issued for all significant tropical cyclones that developed in 1984.															
WARNINGS:	Number of warning days: 130														
		Number of warning days with two tropical cyclones in region: 46													
	Number of warning days with three or more tropical cyclones in region:														

TABLE 3-3.													
		F	REQUE	NCY O	F TYP	HOONS	BY M	ONTH	AND Y	EAR			
VIII	73.N	FEB	MAD	APR	MAV	TIBN	7117	NUC	SEP	O.C.III	NOV	DEC	TOTAL
YEAR	JAN	<u>r ed</u>	MAR	APK	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
(1945-1958)		_			_								
AVERAGE	. 4	. 1	.3	. 4	.7	1.1	2.0	2.9	3.2	2.4	2.0	.9	16.3
1959	0	0	0	1	0	0	1	5	3	3	2	2	17
1960	0	0	0	1	0	2	2	8	0	4	1	1	19
1961	0	0	1	0	2	1	3	3	5	3	1	1	20
1962	0	0	0	1	2	0	5	7	2	4	3	0	24
1963	0	0	0	1	1	2	3	3	3	4	0	2	19
1964	0	0	0	0	2	2	6	3	5	3	4	1	26
1965	1	0	0	1	2	2	4	1	5	2	1	0	21
1966	0	0	0	1	2	1	3	b	4	2	0	1	20
1967	0	0	1	1	O	1	3	4	4	3	3	0	20
1968	0	0	0	1	1	1	1	4	3	5	4	0	20
1969	1	0	0	1	0	0	2	3	2	3	1	0	13
1970	0	1	0	0	0	1	0	4	2	3	1	0	12
1971	0	0	0	3	1	2	6	3	5,	3	1	0	24
1972	1	0	0	0	1	1	4	4	3	4	2	2	22
1973	0	0	0	0	0	0	4	2	2	4	0	0	12
1974	0	0	0	0	1	2	1	2	3	4	2	0	14
1975	1	0	0	0	0	0	1	3	4	3	2	0	15
1976	1	0	0	1	2	2	2	1	4	1	1	0	15
1977	0	0	0	0	0	0	3	0	2	3	2	1	11
1978	0	0	0	1	0	0	3	2	4	3	2	0	15
1979	1	0	1	1	0	0	2	2	3	2	1	1	14
1980	0	0	0	0	2	0	3	2	5	2	1	0	15
1981	0	0	1	0	0	2	2	2	4	1	2	2	16
1982	0	0	2	0	1	1	2	5	3	3	1	1	19
1983	0	0	0	0	0	0	3	2	1	4	2	0	12
1984	0	0	0	0	0	0	4	2	1	5	3	1	16
(1959-1984)													
AVERAGE	. 2	.04	. 2	.6	.8	.9	2.8	3.3	3.2	3.1	1.7	.6	17.3
CASES	6	1	6	15	20	23	73	85	82	81	43	16	451

TABLE 3-4.													
TABLE 3-4.													
	FREQUENCY OF TROPICAL STORMS AND TYPHOONS BY MONTH AND YEAR												
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
(1945-1958)													
AVERAGE	. 4	.1	. 4	. 5	.8	1.3	3.0	3.9	4.1	3.3	2.7	1.1	21.6
1959	0	1	1	1	0	0	3	6	6	4	2	2	26
1960	0	0	0	1	1	3	3	10	3	4	1	1	27
1961	1	1	1	1	3	2	5	4	6	5	1	1	31
1962	ō	ī	0	1	2	0	6	7	3	5	3	2	30
1963	ŏ	ō	ō	ī	ī	3	4	3	5	5	0	3	25
1964	ŏ	ŏ	ŏ	ō	2	2	7	9	7	6	6	1	40
1965	2	2	1	1	2	3	5	6	7	2	2	1	34
1966	0	0	0	1	2	1	5	8	7	3	2	1	30
1967	ì	Õ	2	1	1	1	6	8	7	4	3	1	35
1968	0	0	ō	1	1	ī	3	8	3	6	4	0	27
1969	ì	ŏ	1	õ	0	Ō	3	4	3	3	2	1	19
1970	0	1	0	0	0	2	2	6	4	5	4	0	24
1971	1	0	1	3	4	2	8	4	6	4	2	0	35
1972	1	0	0	0	1	3	6	5	4	5	2	3	30
1973	0	0	0	0	0	0	7	5	2	4	3	0	21
1974	1	0	1	1	1	4	4	5	5	4	4	2	32
1975	1	0	0	0	0	0	2	4	5	5	3	0	20
1976	1	1	0	2	2	2	4	4	5	1	1	2	25
1977	0	0	1	0	0	1	4	1	5	4	2	1	19
1978	1	0	0	1	0	3	4	7	5	4	3	0	28
1979	1	0	1	1	1	0	4	2	7	3	2	2	24
1980	0	0	0	1	4	1	4	2	6	4	1	1	24
1981	0	0	1	2	0	2	5	7	4	2	3	2	28
1982	0	0	3	0	1	3	4	5	5	3	1	1	26
1983	0	0	0	0	0	1	3	5	2	5	5	2	23
1984	0	0	0	0	0	2	5	5	4	7	3	1	27
(1959-1984)													
AVERAGE	.5	. 3	.5	.8	1.1	1.6	4.5	5.4	4.8	4.1	2.5	1.2	27.3
CASES	12	7	14	21	29	42	116	140	126	107	65	31	710

TABLE 3-5.	•												
		FORMATION ALERT S	SUMMARY										
		WESTERN NORTH PACIFIC											
YEAR	NUMBER OF ALERT SYSTEMS	ALERT SYSTEMS WHICH BECAME NUMBERED TROPICAL CYCLONES	TOTAL NUMBERED TROPICAL CYCLONES	DEVELOPMENT RATE									
1972	41	29	32	71%									
1973	26	22	23	85%									
1974	35	30	36	86%									
1975	34	25	25	74%									
1976	34	25	25	74%									
1977	26	20	21	77%									
1978	32	27	32	84%									
1979	27	23	28	·85%									
1980	37	28	28	76%									
1981	29	28	29	97%									
1982	36	26	28	72%									
1983	31	25	25	81%									
1984	37	30	30	81%									
(1972-1984) AVERAGE	32.7	26.0	27.8	₩ 808									
CASES	425	338	362										





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The formation of Tropical Storm Vernon marked the start of the western Pacific tropical cyclone season. This is the second year in a row that the first tropical cyclone of the season did not develop until June, and the first time since JTWC was established that two consecutive seasons have started so late in the year.

Tropical Storm Vernon was very similar to its 1983 season opening counterpart, Tropical Storm Sarah, in that it formed in the South China Sea during June, developed into a weak Tropical Storm, and made landfall in central Vietnam.

The disturbance which was to develop into Tropical Storm Vernon was first detected early on 7 June as an area of poorly organized convection on the eastern end of the monsoon trough in the central South China Sea. The disturbance drifted slowly to the northwest and consolidated during the next 24 hours. At 0411Z on the 8th, a TCFA was issued based on improved organization of the convection and synoptic data which indicated the disturbance had a closed surface circulation with winds of 15 to 25 kt (8 to 13 m/s). Vernon continued moving to the northwest at 5 kt

(9 km/hr) and at 0000Z on the 9th the first warning was issued based on numerous 25 to 30 kt (13 to 15 m/s) ship reports. The MSLP at this time was near 999 mb.

Over the next 18 hours Vernon's forward speed doubled to 10 kt (19 km/hr) as the storm intensified, attaining tropical storm strength between 0000Z and 0600Z on the 9th and reaching a maximum intensity of '40 kt (21 m/s) approximately 6 to 9 hours later (Figure 3-01-1).

Vietnamese authorities reported that Vernon caused flooding of rice, sweet potato, and sesame crops in the Quang Nam-Danang province. No loss of life or other significant property damage was reported.

After reaching maximum intensity, Vernon moved in a more westerly direction at 12 kt (22 km/hr), and began to weaken as the storm entered a strong shearing environment. Vernon continued toward the coast of Vietnam, making landfall just north of Da Nang (WMO 48855) at approximately 101200Z. By this time most of Vernon's convection was sheared to the west of the low-level circulation. Vernon quickly dissipated over land.

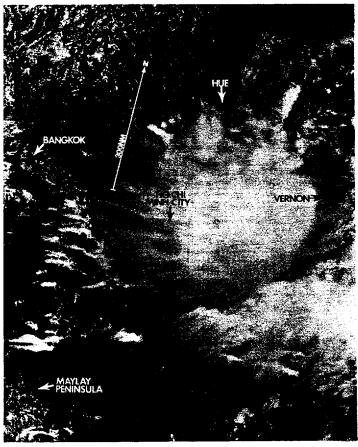


Figure 3-01-1. Tropical Storm Vernon with exposed low-level circulation as it attains tropical storm intensity (090316Z June DMSP visual imagery).

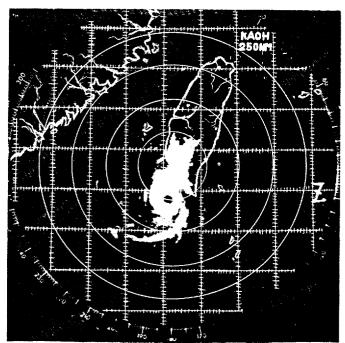
After Tropical Storm Vernon (Q1W) dissipated over Vietnam, the southwest monsoon was slow to re-establish itself. Surface ridging from an anticyclone over the northern Philippine Sea and later from a 1030 mb high east of Japan kept easterlies in the Philippine Sea and across Luzon until the 14th of June. By then the ridge east of Japan had moved far enough east to allow a weak southwest monsoon to become established from the South China Sea eastward into the Philippine Sea. This set the stage for the development of Tropical Storm Wynne.

The disturbance which developed into the second storm of the season was first detected late on 16 June in the northern Philippine Sea as an area of concentrated convection embedded in the southwest monsoon. By 17 June a broad, weak surface circulation had developed near 20N 137E with an MSLP of 1005 mb and 10 to 20 kt (5 to 10 m/s) surface winds. The organization of the convection continued to improve, prompting the issuance of a TCFA at 1600Z on the 18th. At that time, synoptic data indicated a weak upper-level anticyclone had developed aloft providing good outflow to the south and west. Late on the 18th, the first aircraft reconnaissance flight into the disturbance found a 6 nm (11 km) wide surface center with an MSLP of 998 mb and maximum surface winds of 20 kt (10 m/s). At 190933Z the first warning on Wynne, valid at 190600Z, was issued.

Wynne maintained a predominantly westward track throughout its life. The storm was steered by the westward flow along the southern side of the mid to low-level subtropical ridge. This ridge was apparently too narrow to be resolved by JTWC's primary forecast aid, the One-Way Interactive Tropical Cyclone Model (OTCM). As a result, OTCM repeatedly predicted a northward track for the storm. By the second warning, JTWC forecasters had noticed this apparent problem with OTCM and began forecasting a more westward track than OTCM indicated.

On 19 June a mid-latitude trough passed to the north of Wynne causing Wynne to turn briefly to the northwest. However, the trough did not weaken the subtropical ridge enough to allow for recurvature. After the trough passed on the 20th, Wynne once again resumed its westward heading which it maintained until landfall.

Despite the five days Wynne remained in the Philippine Sea east of Taiwan, it did not intensify beyond 55 kt (28 m/s). The weak upper-level anticyclone which developed over Wynne on the 18th remained very small, being overshadowed by a much larger upper-level anticyclone to the north over mainland China. Therefore, Wynne remained under a strong shearing environment from the north and northeast throughout its life, which hindered intensification.



NR: 187 WAYNE 1984.6.23. 1900Z FFAA 23190 46744 48218 1/202 106/2 526/2 OP: WANG

Figure 3-02-1. Tropical Storm Wynne as it passed south of Taiwan as seen by radar from Kaohsuing (WMO 46744) at 231900Z June (Photograph courtesy of Central Weather Bureau, Taipei, Taiwan).

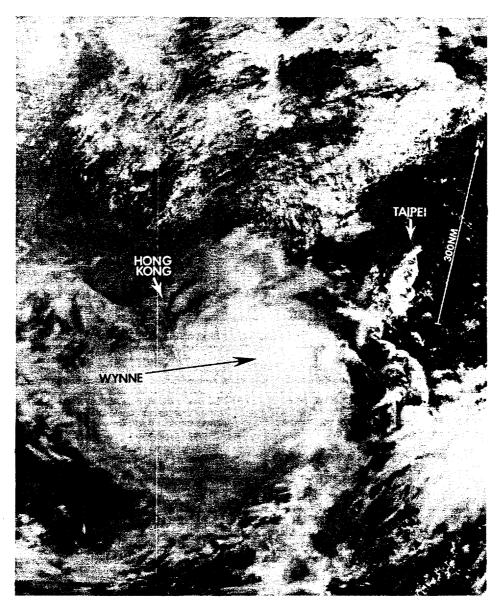


Figure 3-02-2. Wynne as a 50 kt (26 m/s) tropical storm entering the south China Sea [2401362 June DMSP visual imagery].

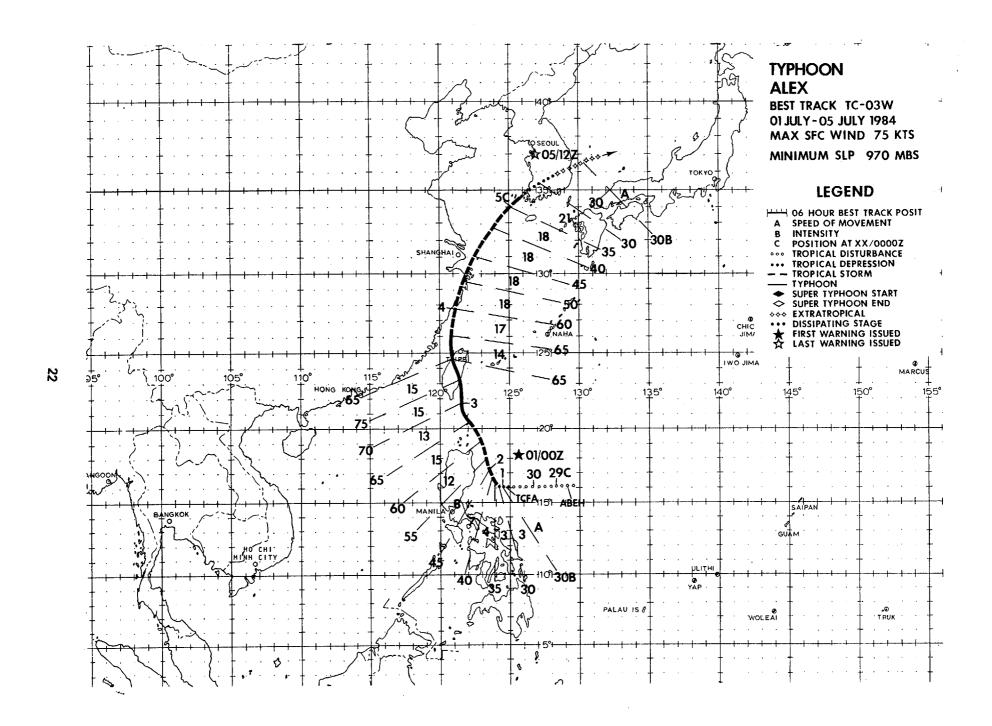
Wynne strengthened to 55 kt (28 m/s) just prior to passing the southern coast of Taiwan. The sea level pressure of Lanyu (WMO 46762), located just east of the southern tip of Taiwan, dropped 14 mb in the 12 hours preceeding the storm's arrival, reaching 984 mb with Wynne's passage. As Wynne passed the southern tip of Taiwan (Figure 3-02-1), its low-level circulation was disrupted causing Wynne to weaken slightly as it entered the South China Sea (Figure 3-02-2).

Wynne passed 70 nm (130 km) south of Hong Kong (WMO 45005) about 24 hours after passing the southern tip of Taiwan. By this time Wynne had intensified to its peak intensity of 60 kt (31 m/s). This was confirmed by the USS Mauna Kea (AE22) which inadvertently passed very close to Wynne's center and reported "maximum winds to 60 kt, gusts to 70 kt." Fortunately, no damage or

personnel injuries were reported aboard the Mauna Kea. Further north, Hong Kong reported gusts to 60 kt (31 m/s) with the passage of Wynne.

As Wynne traversed the Philippine Sea and the northern Luzon Straits, the southwest monsoon was enhanced producing 20 to 30 kt (10 to 15 m/s) winds, high seas and heavy rainfall. In Luzon, at least 20 families were reported left homeless and 10,000 hectares of riceland destroyed by floods. North of Luzon, three fishermen drowned when their boats capsized in heavy seas.

Tropical Storm Wynne made landfall at approximately 1200Z on the 25th on the coast of the People's Republic of China near the Luichow Peninsula, and weakened rapidly as it moved inland. The final warning on Wynne was issued at 0000Z on the 26th.



Typhoon Alex was the first typhoon of the 1984 western Pacific season. It was also the season's first recurver. The satellite fixes during the formative stages of Alex were somewhat misleading and contributed to rather large forecast errors on the first day in warning status. After reaching typhoon intensity and crossing Taiwan, the last phase of Alex's life was characterized by a complex transition into an extratropical low.

The seedlings of Alex first caught the attention of the JTWC forecasters on the $28 \, \mathrm{th}$ of June. Based on several ship reports showing that a circulation center had developed in the Philippine Sea, the Significant Tropical Weather Advisory (ABEH PGTW) was reissued at 281415Z stating that a 10 to 15 kt (5 to 8 m/s) surface circulation had developed near 16N 129E, within a disorganized area of convection in the monsoon trough (point A on Figures 3-03-1 and 3-03-2). This area was identified as one with a "poor" potential for development (meaning the disturbance was not expected to require a TCFA during the advisory period). For the next day-and-a-half the disturbance persisted with no signs of development. At 2301Z on the 29th, visual satellite pictures indicated that a partially exposed low-level circulation had developed on the northern edge of the disturbance (point B on Figures 3-03-1 and 3-03-2). Consequently an aircraft investigation of the area was requested for the following day.

Upon arrival at the invest point, the aircraft radioed back to the JTWC forecaster that a well-defined circulation center was present and that a vortex fix would be forthcoming. Now things happened quickly. The forecaster first notified his customers on Luzon that a tropical depression was developing just to the east of them and they could experience 30 kt (15 m/s) winds within 18 hours. At 2300Z on the 30th a TCFA was issued. Shortly thereafter, at 2338Z, the vortex fix was radioed to JTWC containing details on the closed surface circulation. The first warning on Alex, valid at 0000Z on 1 July quickly followed.

Unfortunately, the first four warnings forecast Alex to move to the west. Satellite fixes starting late on the 29th and continuing through 18002 on the 1st indicated that the depression was moving west-southwest. Limited radar fixes indicated that the system was nearly stationary. However, when the daylight satellite pictures became available late on 1 July, it was obvious that the system had in reality moved north-northwest (along track CD in Figure 3-03-2) and was now a tropical storm. Thus it was not until warning number five that the westward track was abandoned and not until warning number seven that the recurvature scenario was fully developed.

The rationale behind the forecast track on warning number one now becomes instructive: When the system was first detected "on the doorstep" of Luzon, there

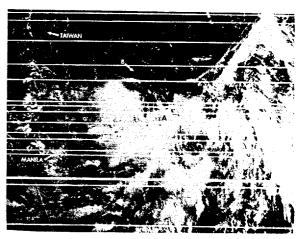


Figure 3-03-1. Initially the exposed low-level circulation center at point B was thought to be the origin of Typhoon Alex. However, post-analysis indicates the actual point of origin was probably near point A (292301Z June NOAA visual imagery).

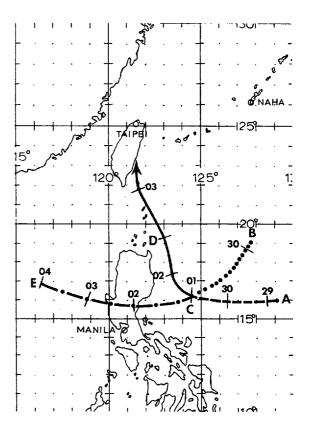


Figure 3-03-2. Point A is believed to be the actual point of origin of Typhoon Alex; Point B is the position of the partially exposed low-level circulation center, initially thought to be the origin of Alex; Point C is the location of the center found by the first aircraft invest; Point D is the best track through 0212007, and Point E is the 72 hour forecast from warning number one.

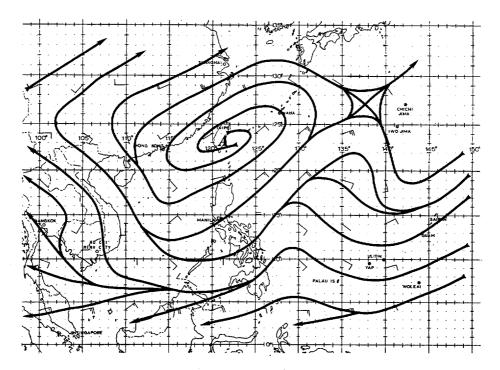


Figure 3-03-3. Mid-tropospheric flow prevailing during the formulation of the first warning forecast reasoning (Streamline analysis of the FNOC 400 mb NVA wind field valid at 3012007 June).

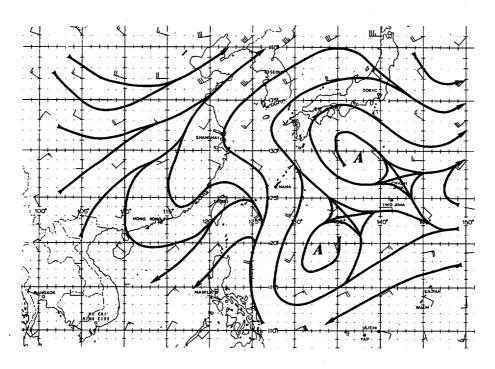


Figure 3-03-4. The mid-tropospheric synoptic situation prevailing during most of the life of Typhoon Alex. Note the anticyclone which has moved east to the south of Japan and the trough over central China which is also moving eastward (Streamline analysis of the FNOC NOGAPS 500 mb wind field valid at 0212007 July).

was an urgency to let the people there know that the potential existed for a tropical cyclone to affect them almost immediately. Therefore it was deemed necessary to devise the forecast track before all of the JTWC forecast aids could be obtained. Available to the forecaster were the past fixes which lead to best track BC on Figure 3-03-2 and a synoptic situation characterized by a midtropospheric ridge north of the storm as illustrated in Figure 3-03-3. Given the present and past position of the storm and the northeasterly flow across Luzon, a westward forecast with recurvature beyond the 72 hour point seemed logical. This scenario was briefed to all concerned. When the forecast aids did arrive, they generally agreed with this reasoning. One of the aids which did not agree was the One-Way Interactive Cyclone Model (OTCM), JTWC's primary forecast aid, which forecast Alex to move to the north-northwest to near point D in Figure 3-03-2 in twenty-four hours. The OTCM forecast was discounted for three reasons. First, it was perpendicular to the mid-tropospheric flow and headed toward the center of the ridge near Taiwan. Second, the track BCD seemed highly improbable. Finally, OTCM had consistently and erroneously forecast a westward moving storm (Tropical Storm Wynne (02W)) to go to the north only a week earlier in the same general area.

As it turned out, the OTCM forecast was excellent. Figure 3-03-4 reflects the new synoptic situation. The anticyclone that had been over Taiwan did not persist as originally anticipated but weakened and moved to the east. This movement allowed Alex to accelerate to the north-northwest towards Taiwan. The OTCM had correctly forecast this to occur. With the postanalysis knowledge that Alex did not transit the Philippines, but instead went northnorthwest, Figure 3-03-2 should be examined for an explanation of the true origin of Alex. The track BCD seems highly improbable There is currently no explanation for a path from B to C at a speed of nearly 10 kt (19 km/hr), a slow down to 3 kt (6 km/hr) at C

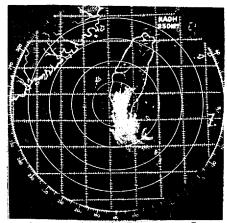


Figure 3-03-5. Typhoon Alex just prior to attaining maximum intensity (0223292 July NOAA visual imagery).

followed by a sudden 120 degree turn to the right and an acceleration to 12 kt (22 km/hr) by point D. A much more likely path would be genesis near point A, as was indicated by synoptic data back on 28 June, westward movement at about 5 kt (9 km/hr) to C and then a more gradual turn to the right with acceleration to D. Consequently it is now thought that the low-level circulation center found by satellite imagery at point B on the 29th of June was a "red-herring"; nothing more than an eddy in the monsoon trough.

Once the northward movement of Alex was well established, the forecasts were relatively accurate (although the speeds were somewhat slow). The only question was whether Alex would track up the east coast of Taiwan, cross the middle of the East China Sea and transit through the Korean Strait, or transfer across Taiwan, move along the coast of mainland China and cross South Korea. By warning number 11 this question was correctly resolved as the last eight warnings had excellent track forecasts. Alex continued to intensify reaching a maximum intensity of 75 kt (39 m/s) just prior to crossing Taiwan (Figures 3-03-5 and 3-03-6). During the middle and last phases of Alex's life, the southwesterlies in front of a trough that laid over central Korea provided the steering mechanism. This trough with its associated surface front was the same trough observed over northern China in Figure 3-03-4 several days earlier. Starting on 5 July Alex underwent a complex extratropical transition with this front. The final warning was issued at 051200Z as Alex became indistinguishable from the frontal system over the Sea of Japan.

In summary, Typhoon Alex can be identified as a typical, well-behaved recurver that transitioned into an extratropical system. The first four warnings were marred by erroneous rejection of OTCM, and by acceptance of early fixes from a feature that was probably not part of the genesis mechanism.



NR: 022 ALEX 1984 7. 2 2300 Z FFAA 02230 44944 48218 11217 35/1/ 50009 90 CHION

Figure 3-03-6. Typhoon Alex just prior to attaining maximum intensity as seen by radar from Kaohsuing (WMO 46744) at 022300Z July (Photograph courtesy of Central Weather Bureau, Taipei, Taiwan).

Tropical Storm Betty originated in the eastern extension of the monsoon trough early in July but took several days to develop into a significant tropical cyclone. Once developed, Betty moved steadily to the northwest through the South China Sea eventually making landfall and dissipating over southern China.

At 0000Z on the 2nd, a disturbance which later developed into Tropical Storm Betty was located approximately 550 nm (1019 km) southwest of Guam. Synoptic data showed the disturbance to be a broad, weak surface circulation with winds of 10 to 15 kt (5 to 8 m/s). Concurrent satellite imagery showed the disturbance as an area of poorly organized convection. Strong surface ridging was present between the disturbance and the developing Tropical Storm Alex (03W) to the north which was then located off the east coast of Luzon. Above this surface ridging a TUTT was providing good upper-level outflow to the north of the disturbance enhancing the convective activity.

When the disturbance was mentioned on the 030600Z Significant Tropical Weather Advisory (ABEH PGTW), it had moved northwest behind now Typhoon Alex (03W) which was located east of Taiwan and moving rapidly northward. With the TUTT providing good upper-level outflow over the disturbance, the convection exhibited a marked increase in organization and intensity over 24 hours earlier.

By 0200Z on the 4th, the disturbance had moved to near 15N 128E and was becoming more organized. At this time the first TCFA was issued on the system. Figure 3-04-1 shows the disturbance at the time the TCFA was issued. Note the banding in the convection and anticyclonic upper-level outflow. Synoptic data indicated that only a broad 10 to 15 kt (5 to 8 m/s) surface circulation was present. Strong ridging still persisted north of the disturbance. This ridging was instrumental in preventing Betty from following a path similar to that of Typhoon Alex (03W).

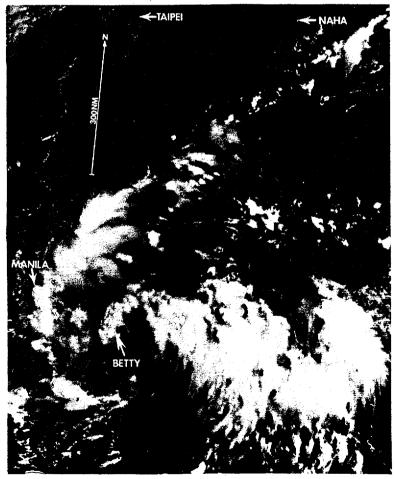


Figure 3-04-1 Tropical storm Betty at the time the first TCFA was issued (0401167 July DMSP visual imagery.

Aircraft reconnaissance flights on 3 and 4 July at the 1500 ft (457 m) level were unable to close-off a circulation center, finding instead a broad surface trough. The TCFA was reissued at 050200Z July since the possibility existed that the system would remain east of Luzon and develop. Aircraft reconnaissance during the afternoon of the 5th indicated that the system had intensified slightly into a weak tropical depression with an MSLP of 1002 mb and maximum surface winds of 25 kt (13 m/s). However, no further development occurred as the system moved west and approached the Philippines.

By the 6th, the depression had weakened as it transited Luzon. At this time the third and final TCFA was issued since it was considered likely that a significant tropical cyclone would finally develop once the disturbance moved out over the South China Sea.

At 1200% on the 6th, synoptic data indicated that the disturbance had moved offshore west of Luzon and was developing. With surface reports of 20 to 25 kt (10 to 13 m/s) and further intensification very likely, the first warning was issued. Visual satellite imagery late on the 6th (Figure 3-04-2) showed Betty, then a depression, with a large, mostly clear area at its center. An exposed low-level circulation is evident as indicated by the spiraling low-level cumulus clouds. Convective activity is heaviest in the southern semicircle surrounding the mostly convection-free center. Aircraft reconnais-sance at about the same time reported a large light and variable center 50 to 60 nm (93 to 111 km) in diameter associated with the depression. Surface winds of 25 to 30 kt (13 to 15 m/s) were observed southeast of the center where the depression's flow was enhanced by the southwest monsoon.

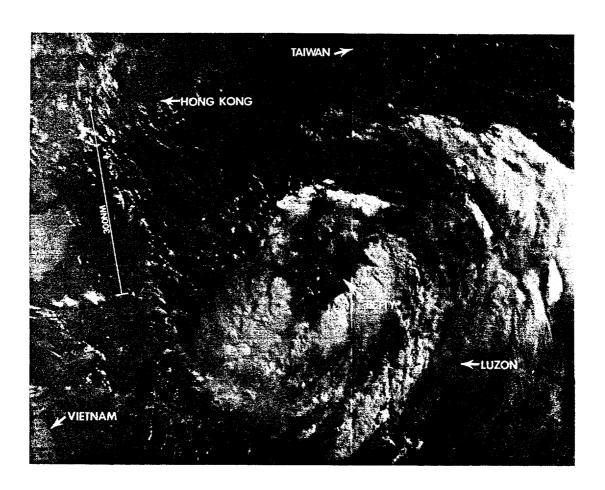


Figure 3-04-2. Tropical Storm Betty as a tropical depression after having crossed the Philippines. Note the exposed low-level circulation center as indicated by spiralling cumulus inside a large convection-free central area [0623337] July NOAA visual imagery).

Betty was upgraded to a tropical storm at 1200Z on the 7th based upon receipt of 35 kt ship reports and satellite imagery showing improved convective organization. Aircraft reconnaissance at 080034Z indicated that Tropical Storm Betty had intensified further with maximum surface winds of 50 kt (26 m/s) being reported in a small area in the east semicircle.

The Hong Kong Royal Observatory (WMO 45005) picked up Betty on weather radar at approximately 080300Z and transmitted position fixes until 090600Z. These hourly reports aided greatly in positioning the tropical storm during this period.

Between 0600Z on the 8th and 0600Z on the 9th, Betty maintained an intensity of 50 to 55 kt (26 to 28 m/s), making landfall at 090300Z approximately 135 nm (250 km) west-southwest of Hong Kong. Figure 3-04-3 shows Betty at maximum intensity just prior to landfall. Dissipation occurred after 091800Z over the southwestern portion of the Peoples Republic of China. No forecast problems were encountered with Tropical Storm Betty since it moved steadily to the northwest around the southwestern periphery of the subtropical ridge.



Figure 3-04-3. Tropical Storm Betty at maximum intensity of 55 kt (28 m/s) just prior to landfall (0901372 July DMSP visual imagery).

Typhoon Cary was the first storm of the season to be initiated by the Tropical Upper Tropospheric Trough (TUTT) in a manner similar to that described by Sadler (1976). While remaining over water its entire life, Cary distinguished itself by unusual intensity changes.

The disturbance which eventually developed into Typhoon Cary was first noticed on the 2nd of July as an area of very poorly organized convection near 18N 168E in the eastern, divergent side of a westward moving TUTT cell. During the next two days, the convection remained poorly organized as it moved to the west-southwest. Surface synoptic data indicated only easterly trades were present beneath the convection. on the 5th, the convection became more organized with satellite imagery indicating an anticyclone developing aloft over the system; however, due to sparse surface reports, the presence of a surface circulation could not be confirmed. Because of the improved organization, the area of convection was mentioned in the 050600Z Significant Tropical Weather Advisory (ABEH PGTW). Subsequent satellite imagery showed continued development of the convection and the ABEH was reissued at 051200Z indicating that the potential for significant tropical cyclone development was "fair" (meaning that it is likely that a TCFA will be issued during the advisory period). Early on the 6th, satellite imagery (Figure 3-05-1) showed that the convection had become comma shaped, with evidence that a surface circulation was forming. Consequently a TCFA was issued at 0603172. During the following 21 hours the disturbance moved to the westnorthwest, with no significant intensification.



Figure 3-05-1. Satellite imagery which prompted issuance of the TCFA. Note the comma shaped convection and the exposed low-level circulation center to the southwest (0600361 July DMSP visual imagery).

Aircraft reconnaissance late on the 6th, had no trouble locating a surface circulation and reported that the disturbance had an MLSP of 1004 mb with estimated maximum surface winds of 25 kt (13 m/s). Based on this report, the first warning on Cary was issued at 0000Z on the 7th. During the next 12 hours, satellite imagery indicated the depression was slowly intensifying. This was confirmed by the next aircraft reconnaissance flight which found Cary had intensified to storm strength with a narrow band of 35 to 40 kt (18 to 21 m/s) surface winds north of its center and an MSLP of 999 mb.

Cary continued to intensify as it moved to the northwest toward an apparent break in the subtropical ridge. Due to uncertainty in the Fleet Numerical Oceanography Center (FNOC) analysis fields in the data sparse region southeast of Japan, 400 mb synoptic track missions were flown on 8 and 9 July to better define the mid-level flow north of Cary. These flights confirmed the presence of a weakness in the ridge, which indicated that forecasts for slow northwestward movement with eventual recurvature to the northeast were sound. Cary slowed as it approached the weakness in the subtropical ridge while continuing to intensify. At 091200Z, Cary was upgraded to typhoon status based on aircraft and satellite data which indicated that a 30 nm (56 km) wide eye had formed, 700 mb flight level winds were 64 kt (33 m/s), and an MSLP of 975 mb existed. During the subsequent 12 hours Cary intensified quite rapidly, reaching a maximum intensity of 90 kt (46 m/s) with an MSLP of 955 mb at 092332Z. Figure 3-05-2 shows Cary just prior to reaching maximum intensity.



Figure 3-05-2. Typhoon Cary just prior to reaching maximum intensity (0922212 July NOAA visual imagery).

Between 0000Z on the 9th and 1200Z on the 10th, Cary moved very slowly through the ridge axis. At the same time, a mid-latitude trough was forecast to deepen in the lee of Japan, supress the subtropical ridge further south, and allow Cary to enter the westerlies and be steered to the northeast. Acceleration, although considered, was not forecast since the strong upper-level westerlies were forecast to remain well north of 30N through the forecast period.

Recurvature to the northeast was underway by 101200Z. This was accompanied by a significant shearing of the convection in the northwest semicircle of the storm (Figure 3-05-3) resulting in a reduction of intensity to near minimum typhoon strength. Approximately 18 hours later the trough approached a blocking ridge along 170E, turned to the north, and weakened. This allowed the shearing environment over Cary to decrease resulting in a gradual increase in convection and a halt to the weakening trend. At 111118Z the ARWO reported that Cary was once again developing an eye; this time 40 nm (74 km) across. This large eye persisted for 24 hours (Figure 3-05-4) as Cary reintensified. Figure 3-05-5 shows the intensity variations of Cary. Note the weakening when Cary was being sheared followed by reintensification as the upperlevel environment improved.

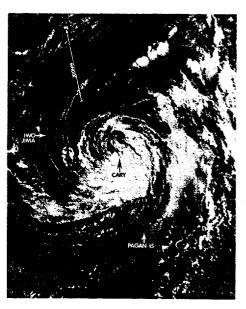


Figure 3-05-3. Typhoon Cary being sheared. Notice the complete absence of significant convection in the northwest semicircle {1021567 July NOAA visual imagery).

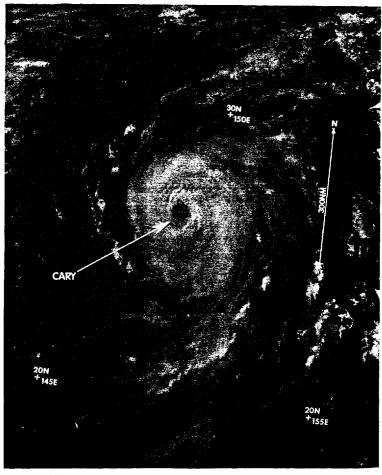


Figure 3-05-4. Typhoon Cary after reintensifying. Maximum sustained winds are 75 kt (39 m/s) (120529Z July NOAA visual imagery).

As Cary moved further north, increasing vertical shear and entrainment of cooler, drier air caused Cary to weaken and gradually become extratropical. By 140600Z Cary had completed its extratropical transition and the final warning was issued. Figure 3-05-6 shows Cary as it completed

transition to an extratropical low. The extratropical remains of Cary continued to weaken and moved west under the influence of a surface ridge northeast of Japan. Cary eventually dissipated to the south of Japan. There were no reports of injuries or damages from Cary.

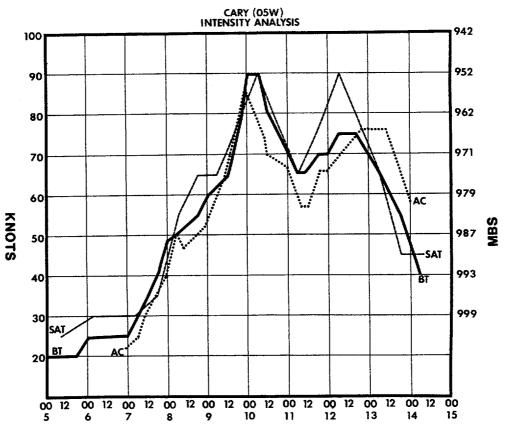


Figure 3-05-5. Satellite (Dvorak, 1973) and aircraft reconnaissance (Atkinson and Holliday, 1977) intensity estimates of Typhoon Cary. Best track intensities are shown as the solid line.

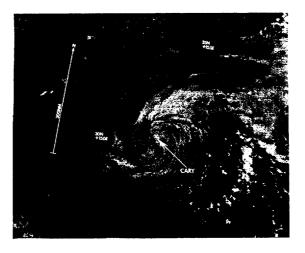
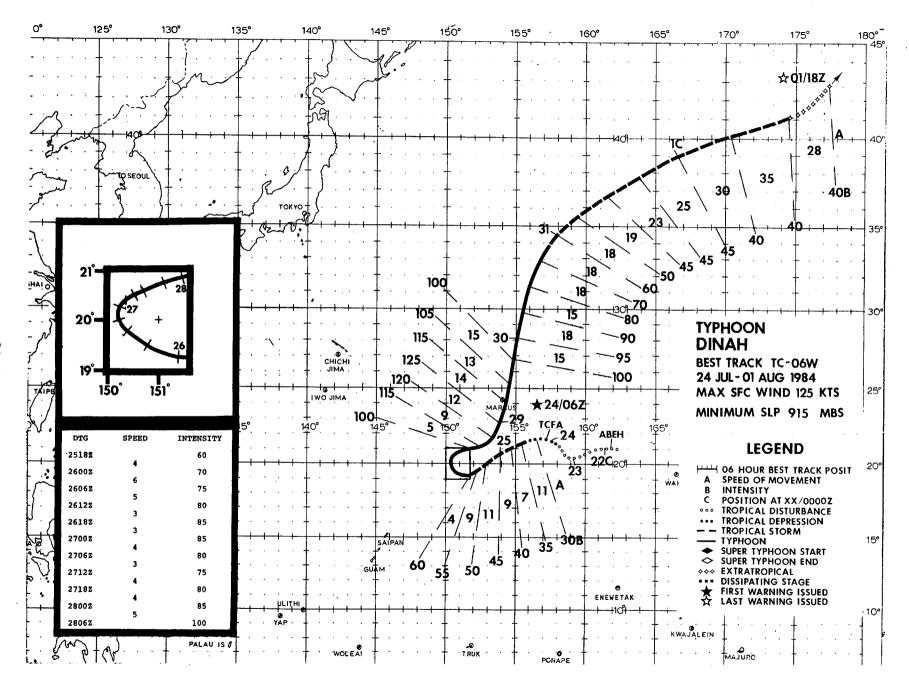


Figure 3-05-6. Cary completing extratropical transition. Note the absence of convection around the storm. Only stable stratocumulus clouds remain (140504Z July NOAA visual imagery).



During much of July, the North Pacific was dominated by slow moving or stationary features. After Tropical Storm Betty dissipated over southern China, the southwest monsoon did not re-develop. Instead, surface ridging was established in the South China Sea. Gradually this ridging spread eastward, and by mid-July dominated the western North Pacific from Southeast Asia to the dateline. This anomalous ridging persisted for almost two weeks. Accompanying this ridging was an almost total absence of significant convection in the tropics. With high pressure dominating the climatologically favored area for tropical cyclone development, it was up to a cold front to provide the genesis mechanism for the next storm of the season. This front had persisted for nearly a week, extending across much of the central North Pacific southwestward to just north of Wake Island (WMO 91245). While the southern end of the associated trough had, at times, shown some convective activity, it was not until the front began to move eastward that the disturbance detached from the front and developed into Typhoon Dinah.

On the 20th and 21st, satellite imagery indicated that the trough and its associated surface front, which had been inactive for nearly a week, were finally moving east. As the trough moved eastward, an area of convection remained behind and began to show some organization. Synoptic data at 1200Z on the 21st indicated a surface circulation had formed beneath the convection, approximately

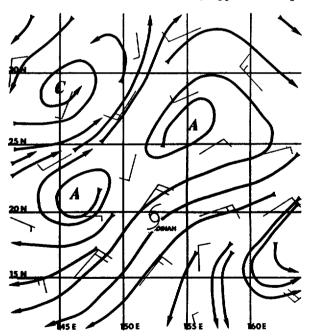


Figure 3-06-1. Mid-tropospheric wind flow which initially steered Typhoon Dinah. Note the ridge to the north with a weakness in the ridge to the northwest (FNOC 400 mb NVA analysis valid at 2512007 July).

300 nm (556 km) to the northwest of Wake Island. During the next two days, the disturbance drifted slowly westward with no significant development. This lack of development and slow movement are attributed to the passage to the north of a developing mid-latitude frontal system which significantly elongated the convection.

Late on the 23rd, with the frontal system passing to the northeast and its influence lessening, the convection associated with the disturbance increased considerably. Based on the 240000Z imagery, a TCFA was issued. As the TCFA was being issued, the first aircraft reconnaissance of the disturbance was already underway. By 240250Z the aircraft had located a 1000 mb circulation center, and had observed surface winds of 30 kt (15 m/s). Since continued development was expected, the first warning on Dinah valid at 240600Z was issued.

During the next two days, Dinah tracked to the west-southwest and intensified. Late on the 25th, Dinah attained typhoon intensity with aircraft reporting that a 30 nm (56 km) wide circular eye had formed. Dinah's track to the west-southwest is attributed to the flow around a narrow mid-tropospheric ridge to its north (Figure 3-06-1). At this time, Tropical Storm Ed (soon to be Typhoon Ed) was moving southeast towards Dinah. This caused the ridge to the north to slide to the east allowing Dinah to turn to the northwest into the weakness.

Between 0000Z on the 26th and 0000Z on the 28th, Dinah and Ed were within 900 nm (1667 km) of each other, with the closest point of approach being at 262100Z when they were approximately 630 nm (1167 km) apart (Figure 3-06-2). While JTWC was warning on these systems it was thought that the major track changes to both were a result of their interaction. However, post-analysis indicates this interaction between Dinah and Ed was not nearly as great a factor as initially thought. It is now believed that the proximity of the storms did not have a major affect on their respective tracks and only a short-lived influence on Dinah's intensity.

Figure 3-06-3 shows the intensity variations of Dinah as measured by reconnaissance aircraft. After intensifying for three days, Dinah weakened for a 12 to 24 hour period on the 27th. This weakening happened after the closest point of approach between the two storms had occurred. The mechanism responsible for this temporary weakening was the well developed outflow of Ed which interacted with Dinah late on the 26th and early on the 27th. Figure 3-06-4 contains a series of three infrared satellite pictures showing the approach and interaction of Ed's outflow with Dinah. This interaction resulted in a significant shearing and suppression of the convection

in the northwest quadrant of Dinah, a temporary weakening of the eye and eyewall and an increase in the central pressure as observed in Figure 3-06-3. Figure 3-06-5 shows an enhanced infrared picture of Typhoon Dinah after interaction with Ed had taken place. Note that the eye is open to the northwest, and there is a lack of significant convection in the northwest quadrant. Although not verifiable, Dinah's brief turn to the east-northeast on the 27th may also be attributable to the pressure from Ed's outflow. By early on the 28th, with the distances between Ed and Dinah increasing, the shearing decreased and Dinah intensified rapidly, reaching its maximum intensity of 125 kt (64 m/s) at

0000Z on the 29th.

By now Dinah was moving to the northnortheast and increasing its forward speed as
the storm tracked along the westward edge of
the mid-Pacific high. At approximately
290600Z Dinah made its closest point of
approach to Marcus Island (Minami Tori Shima
(WMO 47991)) with an intensity of 115 kt
(59 m/s). This was Dinah's only interaction
with land and caused extensive damage to
vegetation on the island. The Coast Guard
Loran station sustained an estimated \$30,000
worth of damage to various buildings and
equipment. Maximum observed winds on the
island were 63 kt (32 m/s) with a peak gust
to 89 kt (46 m/s).



Figure 3-06-1. View of Typhoon Dinah and the developing Tropical Storm Ed (soon to be Typhoon Ed) near the time of their closest point of approach (2622132 July NOAA visual imagery).

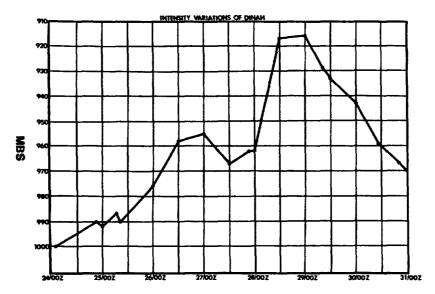


Figure 3-06-3. Intensity variations of Typhoon Dinah as derived from aircraft reconnaissance data.

After passing clear of Marcus Island, Dinah continued to move to the northnortheast at 15 to 18 kt (28 to 33 km/hr) and weaken. Early on the 31st Dinah was downgraded to a tropical storm. A midlatitude trough which had already been interacting with Dinah for approximately 12 hours, now started steering the storm towards the northeast. Transition to an

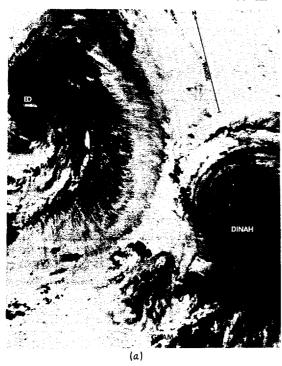


Figure 3-06-4. Three infrared pictures taken during a six hour period showing the approach of Ed's outflow and its interaction with Dinah (a. 2618422 July NOAA infrared imagery, b. 2622142 July NOAA infrared imagery).



extratropical low, which began at about 1200Z on the 30th, was completed by 1200Z on the 1st of August.

The final warning was issued by the Joint Typhoon Warning Center at 1800Z on 1 August. The extratropical remains of Dinah continued to track eastward across the international dateline.



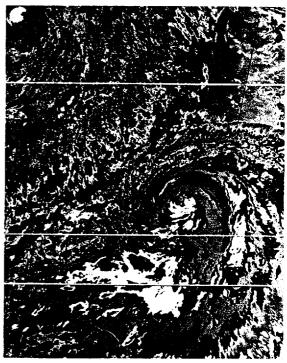
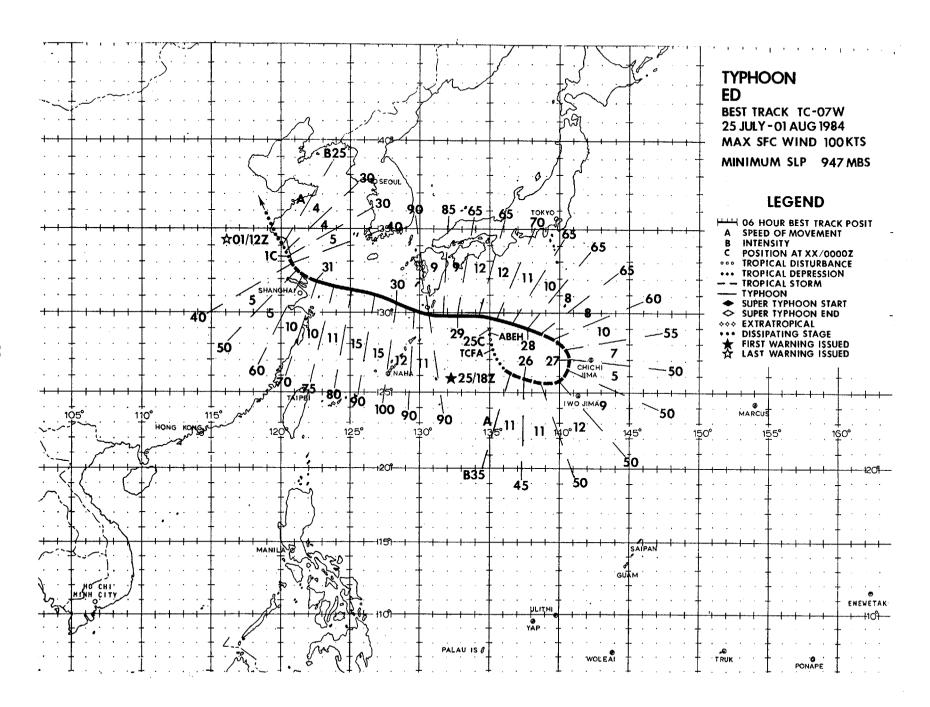


Figure 3-06-5. Enhanced infrared imagery of Typhoon Dinah after interaction with Ed (270545Z July NOAA infrared imagery).



Typhoon Ed, like its predecessor Typhoon Dinah, originated from a mid-latitude system. Forming just south of Japan, Ed initially moved to the southeast, a very unusual direction of movement for tropical cyclones in the northwest Pacific. After briefly interacting with Typhoon Dinah, Ed turned to the west-northwest, a course it maintained until it made landfall on the east coast of China.

The disturbance which eventually developed into Ed began as an area of convection at the southern end of a dissipating cold front transiting Japan. Although the convection was first noticed on 23 July, it was not until late on the 24th that the cloud mass became detached from the front and showed signs of becoming a tropical disturbance. At 0000Z on the 25th, synoptic data indicated a surface circulation had formed, with an MSLP near 1002 mb. Satellite imagery and synoptic data indicated an upper-level anticyclone had developed over the disturbance providing excellent outflow to the south. These developments prompted the Significant Tropical Weather Advisory (ABEH PGTW) to be reissued at 250135Z in order to include this system as a suspect area. The potential for significant tropical cyclone development was assessed as being "fair". Indeed this was an understatement. The area rapidly transitioned from an extratropical feature to a tropical depression as the convection increased and became more organized. At 250600Z, synoptic data showed surface pressures had decreased to 999 mb and Dvorak satellite intensity analysis estimated that surface winds of 30 kt (15 m/s) were present. Consequently a TCFA was issued at 2507452. The disturbance continued to develop overnight and the first warning on Ed was issued at 1800Z on the 25th.

While Ed was developing, Typhoon Dinah located approximately 900 nm (1667 km) to the southeast, was moving to the west and The first five warnings intensifying. forecast Ed to move generally towards Dinah, remain weak and eventually be assimilated into Dinah's inflow. However, Ed did not remain weak but continued to intensify as it moved to the southeast. Aircraft reconnais-sance at 252219Z found Ed had deepened to 985 mb and was supporting winds of 40 to 50 kt (21 to 26 m/s). Ed maintained a 50 kt (26 m/s) intensity during the next 24 hours as it moved closer to Dinah. Throughout this period, Ed's outflow remained very well organized and was elongating to the east towards Dinah. This outflow had a significant short term effect on Dinah's convection and intensity early on the 27th.

During the 26th, a short-wave trough moved eastward across the Sea of Japan. In response to the trough, Ed turned to the north while maintaining its intensity. By 270000Z, the trough had moved to the northeast and was weakening. Ed now came under the influence of a mid to low-level ridge east of Japan. This ridge kept building to the west and forced Ed to move to the west-northwest, a course it maintained until landfall.

While moving to the west Ed slowly intensified, reaching its peak intensity of 100 kt (51 m/s) shortly after passing south of the island of Kyushu (Figure 3-07-1). As Ed transited the East China Sea, entrainment of drier air and passage over cooler waters began to weaken the system. At 0900Z on the 31st, Ed made landfall approximately 60 nm (111 km) north of Shang-Hai (WMO 58367). Maximum sustained winds at landfall were 60 kt (31 m/s). After making landfall, Ed turned to the northwest, transited along coastal China and gradually dissipated. The final warning was issued at 1200Z on the 1st of August.

The only known damage caused by Typhoon Ed occurred to shipping. The Korean registered Ishlin Glory enroute from Pohang, South Korea to Nagoya, Japan sank in the Korea Strait on 29 July. One crew member is known dead, with eleven others reported missing.



Figure 3-07-1. Typhoon Ed near maximum intensity (292242Z July NOAA visual imagery).

Tropical Storm Freda was the first of seven significant tropical cyclones to develop during August. Freda began just as Typhoon Ed was dissipating over eastern China and Typhoon Dinah was completing its extratropical transition well to the east of Japan. In the wake of these two typhoons, the atmosphere had not yet returned to its seasonally normal condition before Freda began to show signs of developing. This situation meant that Freda would be slow to develop and take several days to pull together into a tropical cyclone.

On the 1st of August, just prior to the development of Freda, the western Pacific was dominated at the surface by a deep trough extending southwest from Dinah into a disturbance north of Guam and then southwestward into the southern Philippine Sea (Figure 3-08-1). The southwest monsoon, which had re-established itself during the

last week of July, had not yet returned to its climatological position and would not do so for several more days. The low-level convergence at the base of this trough west of Guam, was the primary genesis mechanism for Freda. By 020600Z, enough convection had developed over the area to merit inclusion of the disturbance in the Significant Tropical weather Advisory (ABEH PCTW). At 021200Z, a closed surface circulation was first analyzed in the Philippine Sea with an estimated MSLP of 1005 mb. The ABEH was reissued shortly thereafter upgrading the potential for significant tropical cyclone development to "fair". An aircraft investigation of the area was requested for the following afternoon. Although at this time it was assumed that the disturbance would progress into a typical tropical cyclone, it would turn out that the most difficult part of warning on this storm would be locating the surface center.

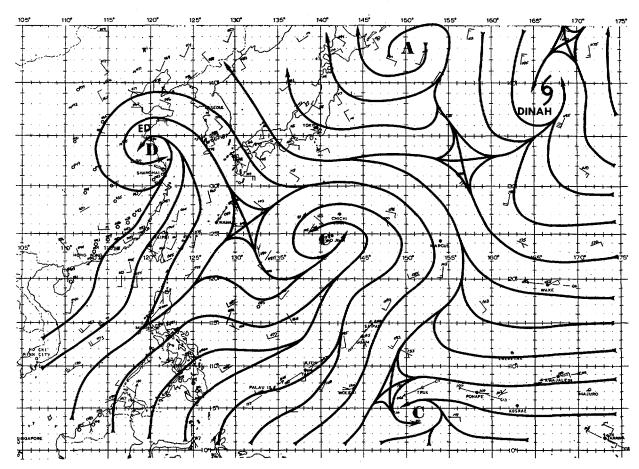


Figure 3-08-1. The 0100007 August 1984 surface/ gradient level analysis. Low-level convergence at the base of the trough west of Guam was the primary genesis mechanism for Tropical Storm Freda.

Since the forecast scenario was not very difficult, and Freda followed a general track to the northwest, the remainder of the discussion will focus of Freda's development through aircraft reconnaissance and the subsequent results.

Mission number one was a resourcespermitting invest on the afternoon of 3 August. It found a very broad, light and variable wind center but could not locate a definite closed circulation. The MSLP reported by the aircraft was 1003 mb. JTWC continued to watch the area and requested another invest for the following morning with a stand-by fix for later that afternoon. The second invest closed-off a 25 kt (13 m/s) circulation near 11.0N 132.7E. However, satellite imagery at that time revealed that the disturbance was developing very slowly. The MSLP observed on the second flight was 1005 mb or two millibars higher than on the previous day - not a promising sign. Since development was occurring so slowly, the afternoon stand-by fix was cancelled and the metwatch continued.

In anticipation of continued slow development during the next twenty-four hours, a TCFA was issued at 040415Z. Two fix missions were also requested for the following day. Mission number three, originally tasked as a fix mission for the morning of 5 August, could not find the system at the forecast location. Reverting to an invest pattern, the crew was still unable to locate a circulation center, although they did find a broad trough some 5 degrees further north than on the previous day. The lowest surface pressure reported was 999 mb. In rapid succession mission number four, the afternoon fix, was cancelled; the TCFA was reissued and positioned further to the northwest; and another aircraft invest was requested for the next morning with a follow-on afternoon fix. At 050716Z, Dvorak satellite intensity analysis of the imagery in Figure 3-08-2 indicated the disturbance was developing and estimated that surface winds of 30 kt (15 m/s) were now present. Based on the satellite intensity estimates, the lower pressures reported by aircraft and the forecast for continued slow intensification, JTWC issued the first warning on Freda as a tropical depression at 051200Z.

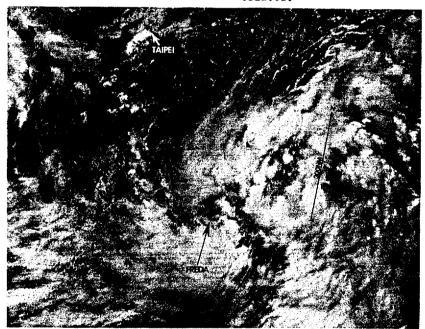


Figure 3-08-2. Dvorak intensity analysis of this imagery indicated 30 kt (15 m/s) winds were present prompting the first warning on Freda (0507162 August NOAA visual imagery).

Mission number five, an invest scheduled for NLT 0600002, finally found a 993 mb circulation center with winds in excess of 35 kt (18 m/s) after several hours of searching. Mission number six, an afternoon fix mission, had little trouble fixing the circulation center of this now 40 kt (21 m/s) tropical storm. At last Freda was showing signs of cooperating; however, this was not to last long! The ARWO on mission number six commented, "This storm was rather weak and unorganized. It was very large and could very well have multiple centers." Indeed

this was the case. Satellite imagery indicated there were now two centers of activity - the second one developing to the north of the circulation fixed by the aircraft (Figure 3-08-3). Up until this time the fixes from both aircraft and satellite as well as the forecast emphasis had been on the southern center, but the northern area was about to assume dominance. The apparent storm movement from 060600Z to 070000Z was as much a reconsolidation around the northern center as it was a simple translation of the entire storm envelope to the northwest. This



Figure 3-08-3. Tropical Storm Freda when reconsolidation about the northern center was about to commence. Note the southern area of convection, where the aircraft and satellite had been fixing the center and a second area of convection located further to the north where the new center would develop [0610107] August DMSP visual imagery]

reconsolidation was complicated by the fact that it occurred at night when only infrared satellite imagery was available. When mission number seven went into Freda the next morning, it could not find a circulation where the southern center should have been. However, when the pattern was changed to that of an invest mission they found Freda located significantly to the northwest within the northern area of convection. The MSLP had now decreased to 988 mb with maximum surface wind of 45 kt (23 m/s) being reported. Mission number eight, the last one flown into Freda, was unable to penetrate the center since the storm had moved over Taiwan.

Freda quickly transited northern Taiwan and the Formosa Straits before making landfall on the Chinese mainland at approximately 071500Z. Like Typhoon Ed, a week earlier, Freda held together over land for two more days before finally dissipating.

In summary, Tropical Storm Freda was a slow developing system that exhibited two centers of action for a portion of its life. The southern center was more dominant until reconsolidation around the northern center occurred just prior to Freda crossing Taiwan. Freda tracked generally to the northwest and was identifiable over land for several days after it moved ashore.

Tropical Depression 09W, just like its predecessor Tropical Storm Freda, was a difficult storm to warn on. The depression's low-level circulation remained weak and poorly organized which made it very difficult to locate. Extensive post-analysis indicates that JTWC warned on the mid-level circulation, which was co-located with the organized convection, rather than the ill-defined low-level center which remained well to the south of the main convection.

Tropical Depression 09W first appeared early on the 7th of August as a broad 1006 mb low in the Near-Equatorial Trough approximately 660 nm (1222 km) south of Guam. The disturbance was mentioned on the 070600Z Significant Tropical Weather Advisory (ABEH PGTW). As it moved to the northwest, the disturbance showed signs of increased organization on satellite imagery, prompting the issuance of a TCFA at 081200Z.

Aircraft reconnaissance on the afternoon of 9 August, indicated that the surface circulation associated with the disturbance was broad and weak. Only 10 to 15 kt (5 to 8 m/s) surface winds were observed with an MSLP of 1004 mb. The TCFA was reissued daily from the 9th to the 11th as the system continued to show convective organization and the presence of a surface circulation in the synoptic data. During this period, the disturbance was very slow to develop a favorable upper-level circulation. The 200 mb flow persisted in being unidirectional (easterly) over the convection. This easterly flow sheared the convection preventing the accumulation of warm, moist air at the low-to-mid levels and the attendant surface pressure drop.

The aircraft reconnaissance investigative flight on the morning of 10 August could not find a surface circulation center. By this time, the system had moved out of the Near-Equatorial Trough and had become the southeastern extension of the monsoon trough.

Between 100600Z and 110600Z, the disturbance moved almost due north. This brought the disturbance under the influence of a TUTT cell located to the northwest near Taiwan. The 200 mb flow over the system now came from the south and was diffluent north through east of the surface circulation. Satellite imagery confirms this by indicating the presence of the heaviest convection in that area. At 110729Z, aircraft reconnaissance closed-off a surface circulation center with 25 kt (13 m/s) surface winds and an MSLP of 1003 mb. Based on the improved upperlevel wind flow and the closed circulation found by aircraft, the first warning on Tropical Depression 09W was issued at 111200Z.

The first six warnings on 09W forecast it to move to the northwest. These forecasts were based on objective forecast aids, including the One-Way Interactive Tropical Cyclone Model (OTCM). Upon post-analysis, these forecasts do not agree well with the synoptic situation present at the time. A low-to-middle level ridge was located to the

north of the depression. In retrospect, the more accurate and synoptically correct forecast, especially with such a weak system as Tropical Depression 09W, would have been a west-northwest to west track along the northern side of the monsoon trough.

Complicating the forecasting of Tropical Depression 09W was the difficulty in positioning the surface center. The surface circulation center was poorly organized because it was embedded in the monsoon trough. The displacement of the mid-to-upper level circulation to the north within the convection, made accurate positioning by satellite imagery of the actual low-level depression center very difficult. Figure 3-09-1 shows one of the few times that the weak, poorly defined, low-level circulation was visible on satellite imagery. Post-analysis of aircraft reconnaissance, synoptic, and satellite data, shows that the depression center, as reflected in the warning positions, was the middle-to-upper level center and not the weak and poorly defined surface circulation center which was located approximately 150 nm (278 km) to the south. JTWC warned on this mid-level feature until 1500002 when the convection finally dissipated over Taiwan and it was obvious that no significant low-level circulation persisted. It is now apparent that the surface center moved along the monsoon trough as a sheared, sometimes exposed low-level circulation from 1112002 to 131800Z and dissipated shortly thereafter as it merged with a cyclonic circulation in the northern South China Sea. This circulation would develop into Tropical Storm Gerald a few days later.

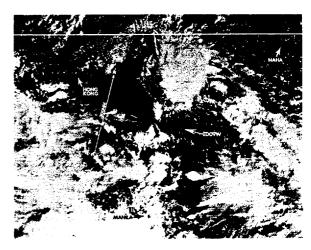
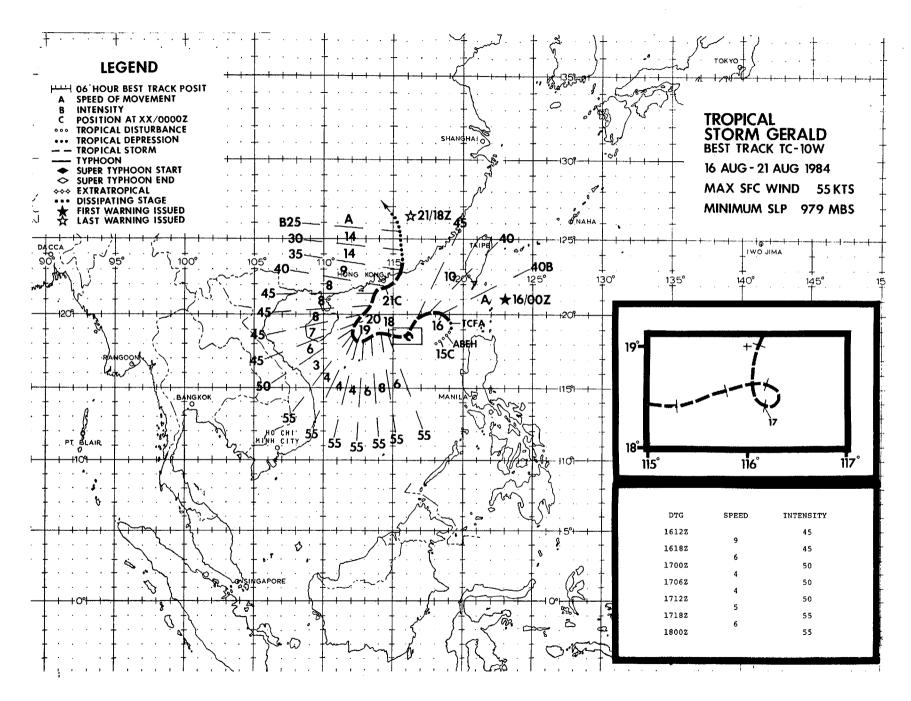


Figure 3-09-1. Tropical Depression 09W passing south of Taiwan. Note the poorly defined exposed low-level circulation located well to the south of the main convection. At the time, the depression's center was thought to be located underneath this convection. However, post-analysis now indicates the exposed low-level circulation was the actual location of the depression's center (1307182 August NOAA visual imagery).



Tropical Storm Gerald led a rather uneventful life. Developing in the northern South China Sea, Gerald remained embedded in the monsoon trough for five days. Its proximity to Typhoon Holly affected both its track and intensity. By the time it made landfall, it had weakened to a minimal tropical storm causing little, if any, damage.

By mid-August, the southwest monsoon had returned to its climatological position. The associated monsoon trough now extended from northern Vietnam across the northern South China Sea and then southeast to just south of Guam. As Tropical Depression 09W developed east of the Luzon Straits, the trough deepened. By the 12th of August, synoptic data indicated a closed surface circulation had formed in the northern South China Sea near 18N 117E with an MSLP near 1001 mb. The circulation continued to develop and at 131200Z the MSLP had decreased to 998 mb with winds near the center of 10 to 20 kt (5 to 10 m/s); 20 to 30 kt (10 to 15 m/s) winds were located south of the circulation center associated with the southwest monsoon.

By 141800Z the convection associated with remnants of Tropical Depression 09W near Taiwan, had nearly dissipated. Up to this point there was very little significant convection in the northern South China Sea. The convection that was present showed no real organization. Between 141800Z and 150000Z, the convection in the northern South China Sea increased considerably. Surface pressures had now decreased to 997 mb. However, winds near the center were light - only 5 to 15 kt (3 to 8 m/s), while

the 20 to 30 kt (10 to 15 m/s) winds still persisted further south - a classic monsoon depression.

The entire monsoon trough had been discussed on the Significant Tropical Weather Advisory (ABEH PGTW) since 130600Z. However, with improved convective organization and lower pressures being observed in the northern South China Sea, this disturbance finally warranted inclusion on its own merits in the 150600Z ABEH.

Synoptic data at 1512002 indicated a broad circulation still persisted, but now 15 to 30 kt (8 to 15 m/s) winds were being reported much closer to the center. This prompted the issuance of a TCFA at 1513272. Less than 12 hours later the first aircraft reconnaissance mission found the system had deepened to 991 mb and was supporting 40 kt (21 m/s) winds near the center. The first warning on Gerald, valid at 1600002, followed shortly.

During the next three days, Gerald moved erratically on a generally westward course, remaining embedded in the monsoon trough. Gerald continued to intensify reaching its maximum intensity of 55 kt (28 m/s) at 171800Z. Gerald then maintained this intensity for the next two days. The inability of Gerald to intensify beyond 55 kt (28 m/s) was due to a strong shear over the storm primarily from the outflow of Typhoon Holly which had developed east of Taiwan on 16 August and persisted throughout most of Gerald's life. This shearing occasionally resulted in the low-level circulation being exposed east of the convection (Figure 3-10-1).

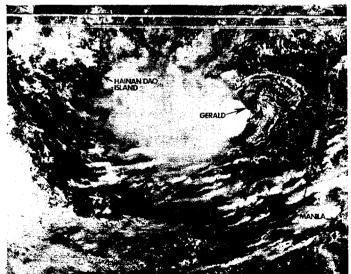


Figure 3-10-1. Example of the partially exposed low-level circulation of Tropical Storm Gerald which was observed periodically during the storm's lifetime. Note the strong easterly flow aloft shearing the convection to the west. This shear was caused by the outflow of Typhoon Holly located far to the northeast (1702002 August DMSP visual imagery).

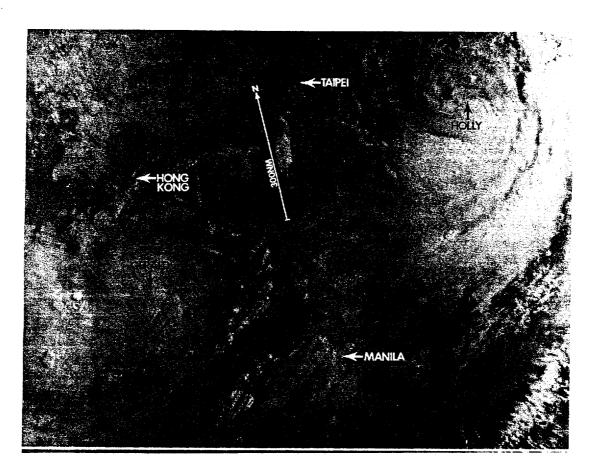


Figure 3-10-2. Tropical Storm Gerald and the developing Typhoon Holly near the time of their closest point of approach. At this time they were approximately 800 nm (1482 km) apart (172327Z August NOAA visual imagery).

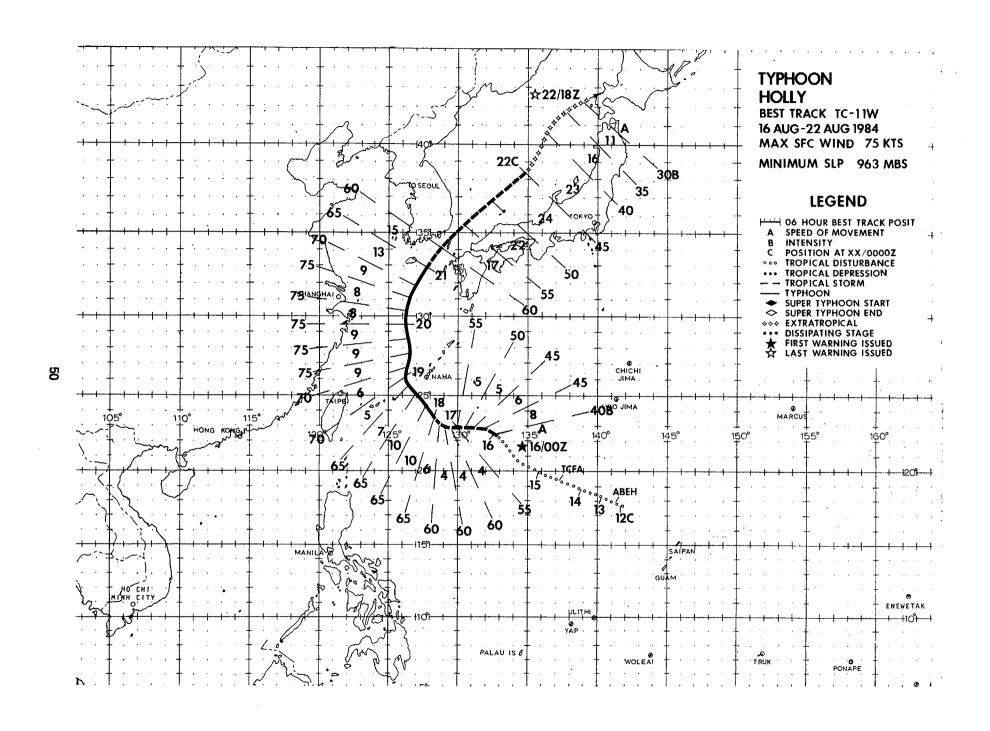
Forecasting Gerald's movement proved to be difficult. Initially most forecast aids and JTWC's official forecast aid called for the storm to move northwest and make landfall over China. However, as Holly intensified and moved west Gerald slowed its westward movement, doing a small cyclonic loop early on the 17th. When Gerald slowed and moved to the south, the forecast scenario changed and called for Gerald to remain quasi-stationary for twelve to twenty-four hours, and then move slowly northeast under the influence of the inflow pattern of the developing Typhoon Holly. Figure 3-10-2 shows Tropical Storm Gerald and the developing Typhoon Holly near their closest point of approach. However, after completing its loop, Gerald once again resumed its westward course as Holly turned to the northwest.

Starting at 191800Z, Gerald turned to the northeast as the very large mid-level circulation of Typhoon Holly, now located

in the East China Sea, again affected Gerald. Accompanying this turn to the northeast was a decrease in the convection as the shearing increased. This began a weakening trend which continued until dissipation.

Gerald accelerated to the northeast and weakened making landfall at 210400Z approximately 50 nm (93 km) east-northeast of Hong Kong (WMO 45005). The closest point of approach to Hong Kong was at 210100Z when Gerald passed 30 nm (56 km) to the southeast.

After making landfall, Gerald turned to the north and weakened rapidly as Holly's influence decreased. Reports from the coastal stations along southern China indicated winds of 20 to 30 kt (10 to 15 m/s) accompanied Gerald as it made landfall. There were no reports of damages as Gerald moved inland over China and dissipated.



Typhoon Holly formed in the eastern extension of the monsoon trough at the same time that Tropical Storm Gerald was forming in the South China Sea. It was the fourth significant tropical cyclone to develop in the trough in less than two weeks. Holly was unusual in that it never was, by definition, a tropical depression. Because it evolved from a very active monsoon trough, Holly was already at tropical storm strength when it finally attained a closed circulation. Despite only reaching a maximum intensity of 75 kt (39 m/s), Holly significantly affected much of the western North Pacific due to its large wind field.

Even as Tropical Depression 09W was transiting the Luzon Straits, synoptic data indicated that a very active trough with poorly organized convection persisted to the At 131200Z the monsoon trough extended from the weakening Tropical Depression 09W eastward to just northwest of Guam. By 141200Z the eastern end of the trough had moved northwest and become sharper. Synoptic data indicated the trough had deepened with an MSLP near 1000 mb. Numerous 20 to 35 kt (10 to 18 m/s) ship reports existed south of the trough axis in the active southwest monsoon. Organization of the convection over the trough also improved during this period, and suggested that a surface circulation was forming. These developments prompted the issuance of the first of two TCFAs at 141515Z.

The first aircraft reconnaissance mission into the disturbance at 0000Z on the

15th found only a sharp trough with 25 kt (13 m/s) surface winds and an MSLP of 998 mb. At 151200Z synoptic data indicated that the southwest monsoon along with a tight pressure gradient between the monsoon trough and the subtropical ridge to the northeast, were now generating gale force winds both north and south of the trough axis. This occurred before any closed circulation was analyzed. These areas of gale force winds were contained in a NAVOCEANCOMCEN Guam (WWPN PGTW) extratropical wind warning bulletin.

The second aircraft investigative mission into the disturbance closed-off a circulation center at 160225Z and found that the MSLP had decreased to 992 mb. Gale force winds were observed within two degrees of the center. The first warning, valid at 160000Z, was issued shortly thereafter with Holly at tropical storm strength.

Determination of the initial intensities of Holly and its associated 30 kt (15 m/s) wind radii were difficult since the gale force monsoon flow extended for hundreds of miles to the south and east of the storm. At first, the monsoon flow was included as a gale area in the NAVOCEANCOMCEN Guam extratropical wind warnings. However, as Holly developed, it took the monsoon flow into its circulation and subsequently became a very large storm. Figure 3-11-1, the 180600Z surface analysis, shows the very large area influenced by Holly. Aircraft and satellite data also indicated that Holly was abnormally large.

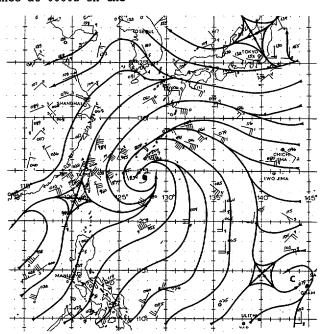


Figure 3-11-1. Surface analysis at 180600Z showing the large circulation of Typhoon Holly. Holly was still consolidating the monsoonal flow into its circulation at this time.

Figure 3-11-2 shows the wind field associated with Holly as reported by reconnaissance aircraft on 18 August. This flight was representative of the data obtained on many of the missions while Holly was a typhoon. The center was characterized by a large area of lighter winds. It was not until the aircraft was more than 60 nm (111 km) from the center that it encountered winds above 50 kt (26 m/s). Generally throughout the life of Holly, the highest winds were found in a band 60 to 150 nm (111 to 278 km) from the center. Within this band, the strongest winds were usually observed in the northern and eastern portions of the storm. The winds observed at Kadena AB, Okinawa confirmed the aircraft reports. The strongest winds observed at Kadena were

in two different periods: from 1713002 to 1809002 and from 1902002 to 1917002 when gusts above 50 kt (26 m/s) were reported. Lighter winds, corresponding to the passage of the huge center, were reported between these periods. The maximum sustained wind reported at Kadena was 50 kt (26 m/s) at 1913552 with a peak gust to 72 kt (37 m/s) at 1908502. Fortunately, despite the strong winds and the 16.76 in (425 mm) of rain, there were no deaths or serious damage reported on Kadena AB. However, some 16,000 air and ferry travelers were stranded on the island during Holly's passage. Figure 3-11-3 shows Holly as it passed west of Okinawa. Notice the very large area covered by Holly's circulation.

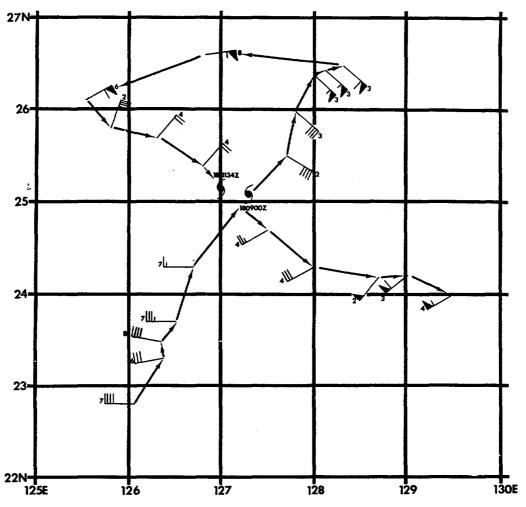


Figure 3-11-2. Plot of aircraft reconnaissance data from the seventh mission into Typhoon Holly. Holly's center was fixed at 1809002 and 1811342 August. Wind barbs are the measured 700 mb winds. The tens digit in the wind direction is plotted with the wind barb.

Holly initially moved to the west under the influence of the subtropical ridge, reaching typhoon intensity at 180000Z. At that time Holly had turned to the northwest, a course it maintained for almost 30 hours. After passing west of Okinawa, Holly turned to the north as it moved around the western periphery of the weakening subtropical ridge. Holly plodded to the north for the next twenty-four hours with no significant intensity changes. At this point the westerlies began to influence the storm. Holly was steered to the northeast and began to accelerate. Holly's forward speed peaked at 24 kt (49 km/hr) just prior to its transition to an extratropical low.

As Holly passed through the Korean Strait, it inflicted considerable damage on the Korean peninsula and the Japanese Island of Kyushu. News reports indicated at least one person killed, nine missing and eleven injured. Property damage was estimated initially at one million dollars. Heavy rainfall accompanied the storm. Miyazake (WMO 47830) on Kyushu recorded 15 inches (381 mm) of rain during a twenty-four hour



Figure 3-11-3. Typhoon Holly passing just west of Okinawa. Notice the large area covered by Holly's circulation (182303Z August NOAA visual imagery).

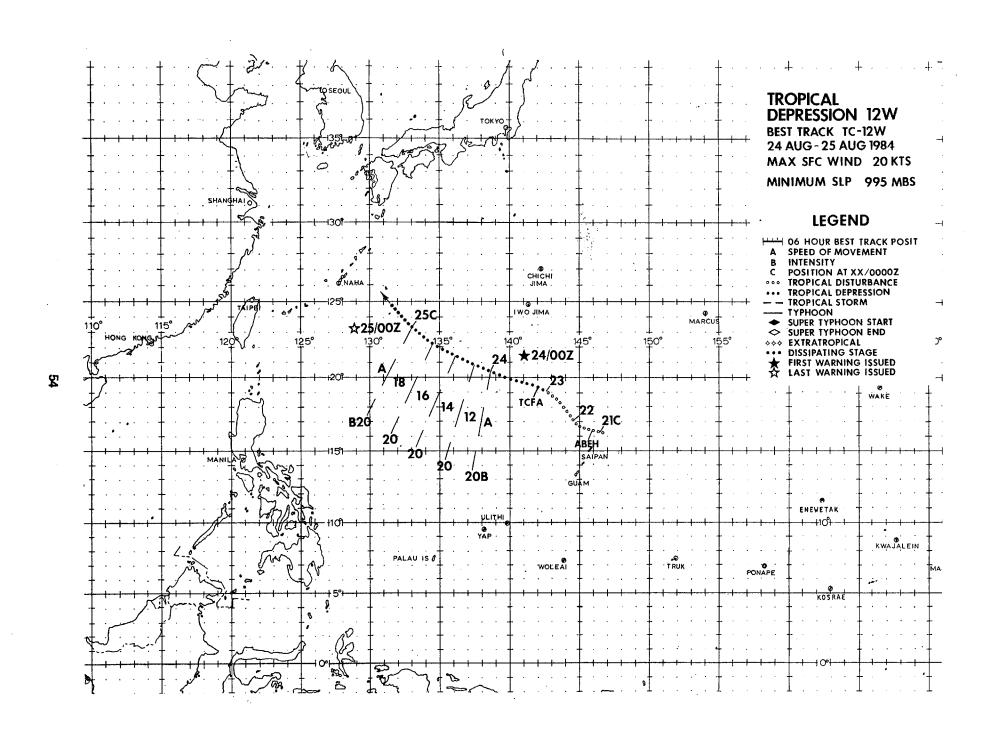
period. Extensive flooding and landslides were also reported.

Holly weakened as it transited the Korean Strait due to interaction with the rugged terrain. As Holly entered the Sea of Japan, it began transitioning to an extratropical system. Figure 3-11-4 shows Holly shortly after completing the extratropical transition. What little convection remains is associated with the front while the exposed low-level circulation is composed of stable stratocumulus clouds. The final warning was issued at 221800Z as Holly neared the island of Hokkaido.

Overall, the JTWC forecasts on Typhoon Holly provided good decision assistance to JTWC's customers. Kadena AB was provided the time needed to evacuate its planes, and South Korea and Japan had sufficient warning time to prepare and thus minimize damage. Even though Holly was not one of the strongest storms of the season, it definitely had a major impact on much of the northwest Pacific.



Figure 3-11-4. Holly after completing its extratropical transition. The low-level center is surrounded by stable stratocumulus clouds. What little convection remains is located southeast of the center and is due to the frontal system and orographic affects [2205262 August NOAA visual imagery).



Tropical Depression 12W developed in the eastern periphery of the monsoon trough, a favorable position for development, but had a very brief existence. Although this system was located in an area of highly convergent low-level flow, the upper-level support, while initially favorable for development was unable to maintain itself and contributed to the depression's dissipation. The combination of a weak low-level circulation and ill-defined mid and upper-level features made satellite fixing difficult, resulting in a wide disparity between fixes. Aircraft reconnaissance also experienced difficulty in fixing this weak system.

The southwest monsoon was slow to re-develop in the wake of Typhoon Holly. Late on 20 August, with a broad trough extending across the northern Philippine Sea, an area of convection began to develop at the eastern end of the trough just to the north of Guam. Synoptic data at 210000Z indicated that a weak 1011 mb closed circulation had formed approximately 200 nm (370 km) northnortheast of Guam. These developments prompted a discussion of the disturbance in the 210600Z Significant Tropical Weather Advisory (ABEH PGTW). The disturbance tracked generally to the northwest during the next two days, and slowly consolidated.

Satellite imagery at 230000Z showed that the disturbance was separating from the trough. Dvorak satellite intensity analysis estimated that surface winds of 25 kt (13 m/s) were now associated with the system. The first aircraft reconnaissance mission was already underway, but could only find a broad weak circulation. No winds greater than 20 kt (10 m/s) were observed. During this time, a weak, upper-level anticyclone developed over the convection. Its development was aided by a TUTT cell located approximately 6 degrees to the west which provided good divergence aloft. These factors contributed to the issuance of a TCFA at 230500Z.

During the following 18 hours the disturbance showed little change. An aircraft reconnaissance mission the next morning fixed a broad wind and pressure center, with an MSLP of 999 mb. Once again no winds greater than 20 kt (10 m/s) were observed within 250 nm (463 km) of the center. Dvorak satellite intensity estimates now indicated that maximum sustained winds of 30 kt (15 m/s) were present and forecasted 35 kt (18 m/s) winds in 24 hours. Synoptic data revealed that 30 kt (15 m/s) winds were indeed present, but they were located approximately 250 nm (463 km) northeast of the disturbance's center, and were associated with the tight pressure gradient between the subtropical ridge located north of Marcus Island (Minami Tori-Shima (WMO 47991)) and the disturbance. However, upper-level support remained favorable for some intensification which meant that the disturbance would pose a threat within 36 hours to the military and civilian populations on the Ryukyu Islands. Accordingly, the first warning on Tropical Depression 12W was issued at 240000Z.

The favorable upper-level support proved to be short-lived. Visual satellite imagery at first light the next morning (Figure 3-12-1) revealed an exposed lowlevel circulation with the associated convective activity displaced several hundred miles to the north. Upper-level synoptic data indicated the TUTT cell had moved northwest to near Taiwan, and the convection had sheared to the north, remaining in the divergent region east of the TUTT cell. There was no longer any evidence of an upper-level anticyclone over the depression. The upper-level flow pattern over Tropical Depression 12W was now dominated by 30 to 50 kt (15 to 26 m/s) easterly winds from a large anticyclone which had been present near Japan for several days. This flow was sufficient to prevent the redevelopment of any significant convection near the low-level circulation center. With further development now

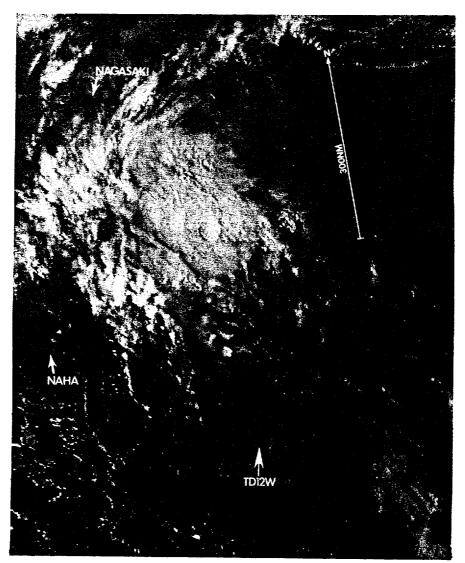


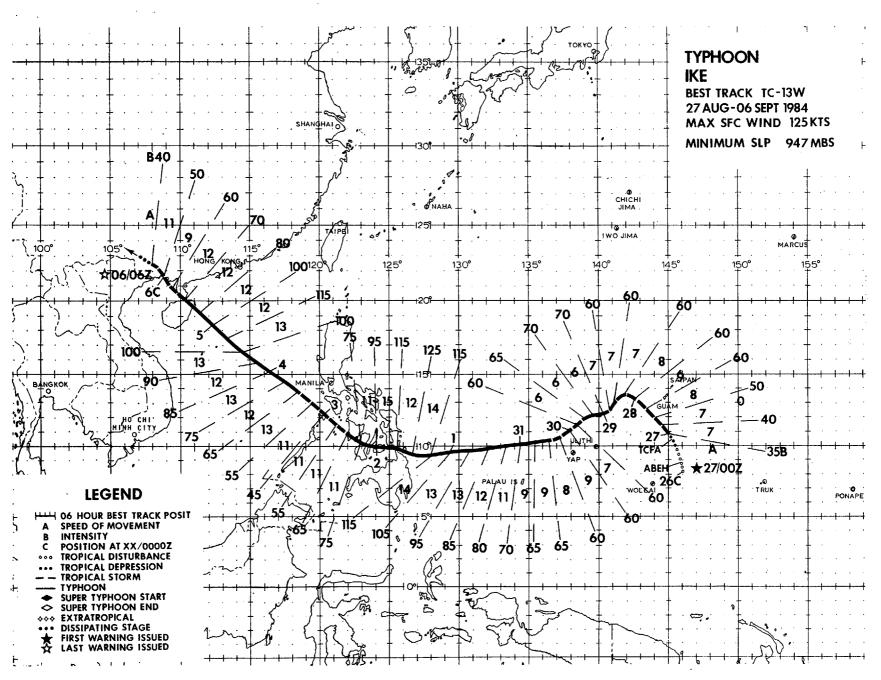
Figure 3-12-1. Exposed low-level circulation of Tropical Depression 12W. The convection which was colocated with the low-level circulation 24 hours earlier is now displaced to the north (2422192 August NOAA visual imagery).

unlikely, the final warning was issued at 0000Z on the 25th.

There were a total of four aircraft reconnaissance missions flown into this system, but only two could fix a center, and both of these had large meteorological and navigational errors. The maximum surface or 1500 ft (457 m) winds found within 200 nm (320 km) of the center were 20 kt (10 m/s). The minumum sea-level pressure found by aircraft was 995 mb at 240708Z which could support 35 kt (18 m/s) winds according to

Atkinson and Holliday (1977). However, no such winds were observed with Tropical Depression 12W.

The exposed low-level circulation, completely void of convection, was tracked northwest after the final warning was issued with 15 to 20 kt (8 to 10 m/s) winds and pressures near 1000 mb being reported. This circulation crossed the Ryukyu Islands near Okinawa before merging with a weak midlatitude front in the northern East China Sea late on 26 August.



The deadliest typhoon to strike the Philippines this century began innocently enough as a weak disturbance on the eastern end of the monsoon trough. After passing Guam as a developing tropical storm, Ike turned to the west-southwest and gradually intensified. Four days later, Ike attained an intensity of 125 kt (64 m/s) and crossed the central Philippines causing extensive damage and over 2000 deaths. After wrecking havoc on the Philippines, a weakened Ike moved into the South China Sea where it reintensified to 115 kt (59 m/s) before making landfall and finally dissipating over mainland China.

As early as 21 August, a weak surface circulation was being analyzed southeast of Guam on the eastern extension of the monsoon trough. From the 21st through the 25th, various Trust Territory of the Pacific Islands reporting stations and ship observations indicated that a weak 1009 mb low persisted in this area. The lack of development of this circulation during this period was attributed to the strong winds aloft from the same anticyclone that sheared Tropical Depression 12W.

Late on the 25th the upper-level shearing began to decrease. This resulted in a rapid increase in the convection over the low-level circulation center. By 260000Z the disturbance, which was to develop into Ike, began to show continuity. Synoptic data at 261200Z indicated the disturbance was intensifying with 20 to 35 kt (10 to 18 m/s) winds being reported on the southern periphery of the circulation center. The MSLP of the disturbance was estimated to be near 1006 mb.

At 2100Z on the 26th, a TCFA was issued based on the earlier mentioned synoptic reports and satellite imagery which showed rapid development of a compact circulation (Figure 3-13-1). Due to the persistent improvement in organization and the proximity of the disturbance to Guam, the first warning on Ike was issued a few hours later at 27000Z.

The initial forecast track called for Ike to move to the northwest. This forecast was based on persistence and the One-Way Interactive Tropical Cyclone Model (OTCM), the best forecast aid currently available to the Joint Typhoon Warning Center. Based on the location of the system and the forecast track, Guam was placed in Condition of Readiness III at 270530Z. This was the first time since 1 December 1982 that Guam had been in other than Condition of Readiness IV. (At that time Typhoon Pamela was approaching from the east.)

The first aircraft reconnaissance flight into Ike fixed the center at 270510Z approximately 120 nm (222 km) south of Guam with an MSLP of 997 mb and estimated the maximum surface winds at 35 kt (18 m/s). Ike continued moving to the northwest at a speed of 7 to 9 kt (13 to 17 km/hr) during the next 24 hours and intensified. The storm remained compact as it passed 90 nm (167 km) southwest of Guam. At its closest point of approach to Guam, Ike supported winds of 50 to 60 kt (26 to 31 m/s) but due to the compact circulation, Guam suffered no ill effects from the storm. The Naval Oceanography Command Center (NAVOCEANCOMCEN) on Nimitz Hill recorded only 15 kt (8 m/s) sustained winds with a peak gust to 21 kt (ll m/s) during Ike's passage. Guam returned to Condition of Readiness IV at 272130Z based on the 271800Z warning position and forecast track.

After passing to the southwest of Guam, Ike continued tracking to the northwest for the next 12 hours. At approximately 0600Z on the 28th, Ike reached the northern most latitude it would attain in the Philippine Sea. At that time Ike was located 160 nm (296 km) due west of Guam. For the next four days Ike would track towards the Philippines on a west-southwest course.



Figure 3-13-1. Early morning picture of Tke at the time the TCFA was issued. A developing upper-level anticyclone is providing good outflow channels to the south and west {2621312 August NOAA visual imagery}.

This change in track was due to the effects of the subtropical ridge south of Japan. From the 26th to the 28th, this ridge was orientated from east to west. However, as Tropical Storm June (which developed over the western Philippine Sea on 28 August) moved westward, the ridge built south in June's wake and took on a more north-south orientation. This forced Ike on a generally west-southwest course until it neared the central Philippines. Between 271800Z and 281800Z, Ike did not increase in intensity due to strong shearing of the convection from the north.

Late on the 28th, the shearing decreased slightly which allowed Ike to intensify to typhoon strength. During this intensification the Atkinson and Holliday (1977) pressure-wind relationship did not hold. For example, at 282341Z aircraft reconnaissance reported surface and flight level winds of 75 kt (39 m/s), yet the MSLP was only 991 mb. This would normally be expected to support winds of 45 kt (23 m/s), some 30 kt (15 m/s) less than what was being observed. After moving almost due west for 12 hours, Ike again turned to the southwest. During this time Ike weakened to below typhoon force due to the persistent strong shearing aloft. However, this weakening was to be temporary.

As Ike turned more to the west on the 30th, the upper-level anticyclone over Ike redeveloped and the weakening trend ceased. By 301200Z Ike had regained typhoon intensity. During this second intensification

period the pressure-wind relationships were in better agreement. At 302310Z aircraft reconnaissance found the MSLP had decreased to 971 mb and reported 700 mb flight level winds of 65 kt (33 m/s). This was in much better agreement with the 70 kt (36 m/s) winds expected by Atkinson and Holliday (1977). During this second intensification, Ike's circulation became larger - more typical of a WESTPAC typhoon.

For the next two days Ike tracked toward the central Philippines at an average speed of 12 kt (22 km/hr) and doubled in intensity. Figure 3-13-2 shows Ike as it neared the Philippines. On the 1st of September just prior to hitting the Philippines, the last aircraft reconnaissance flight was made. The lowest MSLP found was 947 mb at 010845Z and 700 mb flight level winds of 117 kt (60 m/s) were measured in the eyewall of a 25 nm (46 km) circular eye. The maximum surface winds were estimated at 120 to 130 kt (62 to 67 m/s).

For the next 30 hours Ike cut a path of death and destruction across the central Philippine Islands that is unequaled in recent history (Figure 3-13-3). In the wake of its path, Ike left a reported 1026 people dead, with 1147 people missing and presumed dead. Published figures for the number of people left homeless in the central Philippines range from 200,000 to 480,000. The worst hit region was the Surigao del Norte Province of Northern Mindanao where approximately 1000 people died (Figure 3-13-4).

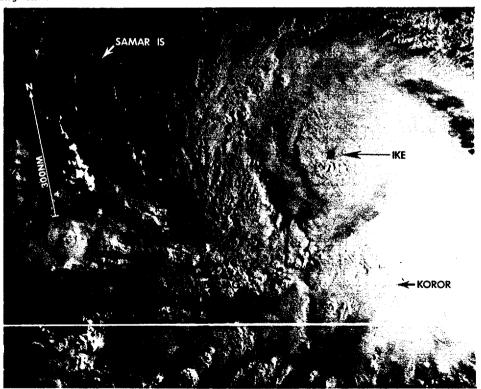


Figure 3-13-2. Typhoon Ike intensifying as it nears the Philippines. At this time Ike was supporting winds of about 105 kt {54 m/s} {3122522 August NOAA visual imagery}.

Ike tracked to the west-northwest and then to the northwest at an average speed of 11 kt (20 km/hr) as it crossed the Philippines and weakened. At 00002 on the 3rd of September Ike had weakened to 45 kt (23 m/s). Ike quickly reintensified as it moved into the South China Sea attaining typhoon intensity by 0312002. Aircraft reconnaissance penetrating the 30 nm (56 km) wide eye at 030843Z found 65 kt (33 m/s) winds at the surface and 68 kt (35 m/s) winds at 700 mb. Ike continued to track steadily to the northwest at 12 to 13 kt (22 to 24 km/hr) reaching an intensity of 115 kt (59 m/s) at 041800Z. Ike gradually lost intensity from this point on, due to the proximity of land restricting the inflow, and shearing from a trough passing to the north.

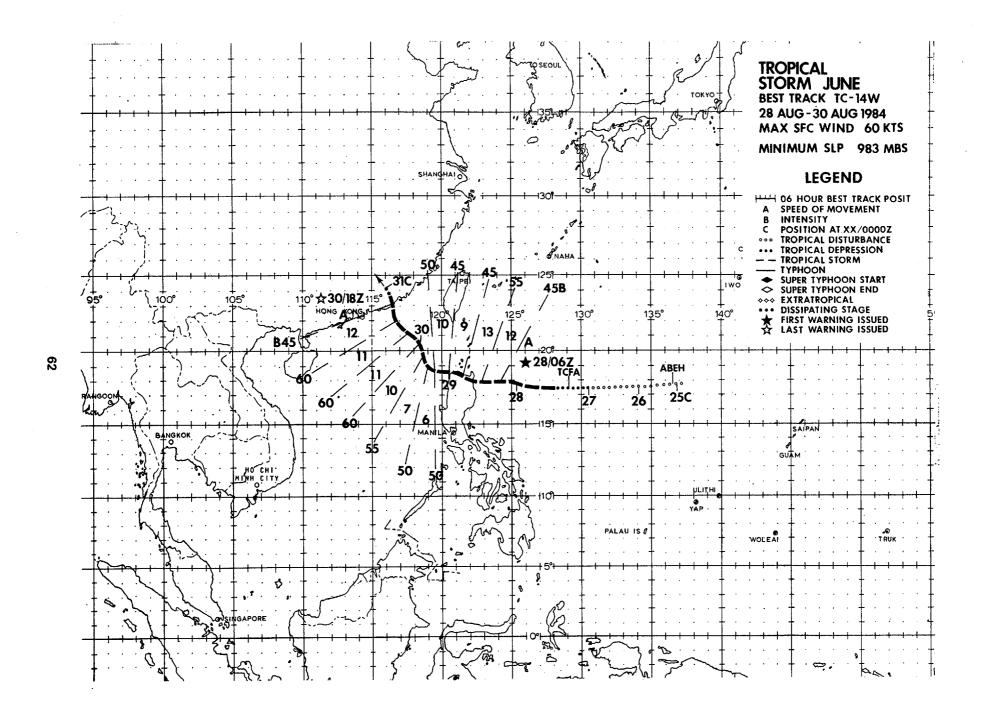
Ike transited across Hainan Island on 5 September still packing winds of 70 to 80 kt (36 to 41 m/s). Shortly after 0000Z on the 6th, Ike crossed the coast of mainland China, as a tropical storm, approximately 60 nm (111 km) south-southeast of Nan-Ning (WMO 59431). News reports indicate Ike was responsible for at least 13 deaths in China. Extensive flooding and crop damage were also reported as Ike moved inland and dissipated.



Figure 3-13-3. Ike as it crossed the central Philippines. At this time Ike was supporting winds of about 90 kt [46 m/s] [020141Z September DMSP visual imagery].



Figure 3-13-4. Aerial reconnaissance photo of a town in Northern Mindanao showing some of the damage caused by Typhoon Ike. (Photo provided by CDR M. McCallister, Naval Oceanography Command Facility, Cubi Point).



Tropical Storm June, the last of seven significant tropical cyclones to develop during August, originated in the monsoon trough like most of the other storms before it. June would also be typical of several other storms during the month, in that the most difficult part of warning on the system would be in locating the actual surface center.

Even as the final warning was being issued on the exposed low-level circulation of Tropical Depression 12W, satellite imagery indicated a large area of convection persisted further south over the active monsoon trough (Figure 3-14-1). At 1200Z on the 25th of August, synoptic data indicated a closed 1000 mb circulation had formed in the trough. During the next two days this circulation drifted westward as the associated convection tried to consolidate. Strong upper-level shearing, from the same anticyclone which sheared Tropical
Depression 12W, inhibited development on the
25th and 26th. But early on the 27th, an
upper-level anticyclone began to form over the disturbance making conditions more favorable for development. Although synoptic data clearly indicated a surface circulation was present during this time, the low-level center was not consistently locatable on satellite imagery within the broad area of convection. This problem would plague JTWC throughout the life of Tropical Storm June.

The first aircraft reconnaissance mission into the disturbance at 270651Z found a closed 30 kt (15 m/s) circulation with a light and variable wind center 50 nm (93 km) in diameter. Based on this information and indications from satellite imagery that the convection was becoming more organized, a TCFA was issued at 270800Z. As typical with most monsoon disturbances, the strongest winds were observed south of the circulation center and associated with the southwest monsoon.

During the following 18 hours, synoptic data indicated the disturbance continued to intensify. However, the convection failed to show the expected increase in organization. During much of this time satellite imagery actually indicated multiple circulation centers were present! Although JTWC wanted to go to warning status on this disturbance as early as 2712002, the inability to accurately position the surface center made this impossible. The area of gale force winds, however, were covered in the NAVOCEANCOMCEN Guam, extratropical wind warning bulletin (WWPN PGFW).

Between 280000Z and 280600Z the disturbance finally consolidated into a single circulation center (Figure 3-14-2). Aircraft and satellite fixes now began to consistently agree on the location of that center. This prompted the issuance of the first warning on June as a tropical storm at 280600Z.



Figure 3-14-1. Active area of convection in the northern Philippine Sea associated with the southwest monsoon which would later develop into Tropical Storm June. Note the exposed low-level circulation further north which is the remnants of Tropical Depression 12W (250630Z August NOAA visual imagery).

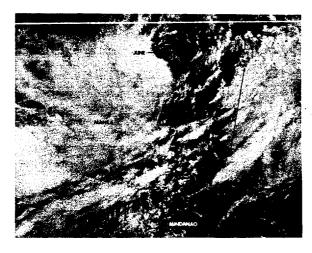


Figure 3-14-2. The developing Tropical Storm June east of the Philippines. At this time June was consolidating about a single circulation center [2807347 August NOAA visual imagery].

At the time of the first warning, Tropical Storm June was located 110 nm (204 km) east of Luzon. June was a broad circulation with the strongest winds in a band 60 to 150 nm (111 to 278 km) from the center. During the next 12 hours June headed west steered by the flow along the south side of a mid to low-level subtropical ridge. The storm made landfall on the east coast of northern Luzon at about 2815002.

After landfall synoptic data indicated the surface circulation of June apparently

tracked to the west-northwest following the low-level terrain over northern Luzon and re-emerged on the northwest coast at approximately 290000Z. However, the mid-level circulation and nearly all of the convection continued to move almost due west. Since the passage over Luzon occurred at night when only infrared imagery was available, accurate positioning of the low-level center from satellite imagery was impossible.

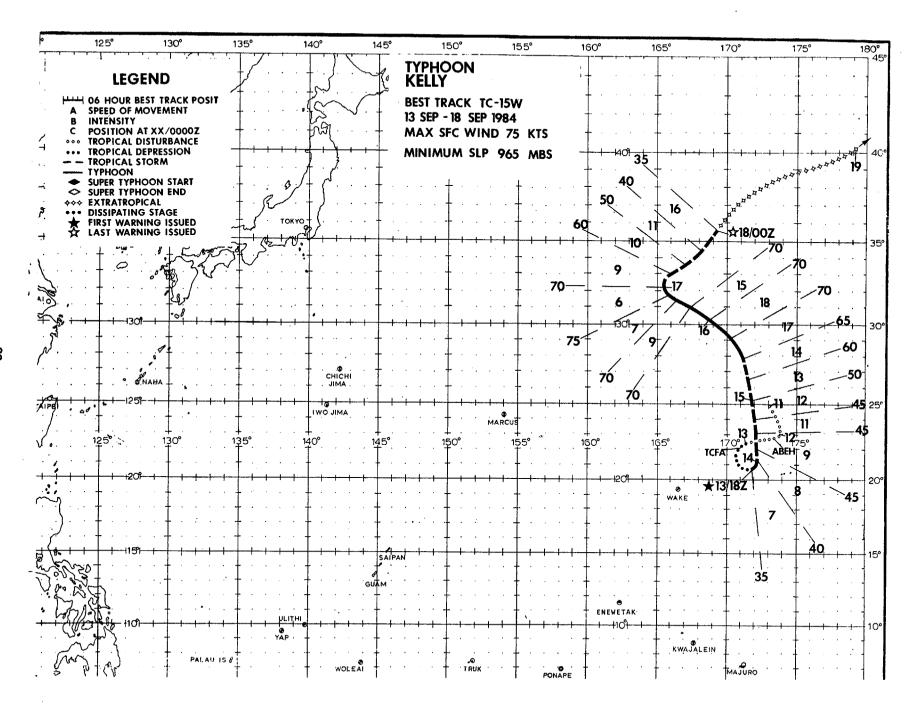


Figure 3-14-3. Tropical Storm June in the northern South China Sea. The broad surface circulation is located north of the convection. This is one of the few times that satellite imagery would be able to accurately fix the low-level circulation of June as it transited the South China Sea (292340Z NOAA visual imagery).

As June emerged in the northern South China Sea a mid-latitude trough moved across eastern China and weakened the subtropical ridge. This allowed June to turn to the northwest. June made landfall at approximately 301700Z on the coast of mainland China 130 nm (241 km) east of Hong Kong (WMO 45005). Although June did intensify to 60 kt (31 m/s) as it transitted the northern South China Sea, the storm remained poorly organized (Figure 3-14-3). During this time aircraft and radar were the only accurate and consistent means of locating the circulation center.

Tropical Storm June was the first named

tropical cyclone of the 1984 season to directly strike the Philippines. Heavy rains from the combination of June and the southwest monsoon caused extensive flooding throughout much of Luzon, particularly along the west coast and in river valleys. At least 67 deaths were attributed to the storm. The deaths resulted primarily from heavy rains, flooding and the accompanying landslides. In addition to extensive damage to crops and vegetation, over 25,000 families lost their homes. However, despite the considerable damage caused by June, it was relatively minor compared to the death and destruction Typhoon Ike brought to the central Philippines only four days later.



Typhoon Kelly was quite representative of the first half of the 1984 season which was characterized by numerous high latitude, fast-moving systems. This typhoon developed at the southern end of a shear line and displayed some erratic movement during its formative stages before accelerating to the north-northwest towards a mid-level cut-off low. During the last phase of its life, Kelly recurved very sharply to the northeast and transitioned into an extratropical system.

During the first week of September, a strong frontal system moved across the North Pacific Ocean and left in its wake a quasistationary shear line extending between 20N 170E and 35N 180E. On 11 September the southern portion of the shear line became detached and began to take on tropical characteristics.

During the next two days the disturbance slowly developed as the associated convection increased in organization. At 0000Z on the 13th, an exposed low-level circulation was observed on satellite imagery west-northwest of the main convection. Dvorak intensity analysis of the 130000Z imagery estimated that 30 kt (15 m/s) surface winds were present near the center. Sparse synoptic data indicated a 20 to 25 kt (10 to 13 m/s) circulation was present. Based on this information, a TCFA was issued at 130435Z and an aircraft investigative mission was requested for the following morning. Throughout the evening the system continued to develop with the convection showing a

considerable increase in organization. This prompted the issuance of the first warning at 131800Z. While this was occurring in the south, a mid-level cold core low was developing further north on the northern remnants of the shear line. This cut-off low and the mid-latitude westerlies just north of it would be the principal steering mechanisms for Kelly.

As long as Kelly stayed below tropical storm strength it moved slowly. Satellite fixes on the 13th indicated Kelly moved in a cyclonic loop about its point of origin. However, after it became a named storm, Kelly accelerated to the north and eventually to the northwest as it was caught in the southerlies between the mid-Pacific high and the inflow pattern about the cutoff low. Because of its relatively high latitude, Kelly entrained cold air into its circulation almost from the start, and was slow to intensify. By 141800Z there was a noticeable "dry slot" forming and the storm took on a north-south orientation (Figure 3-15-1).

As Kelly approached the cold low (Figure 3-15-2) it slowed and reached maximum intensity. Then suddenly, under the influence of the mid-latitude westerlies just to the north, it abruptly turned and accelerated to the northeast. Although JTWC forecasts indicated recurvature to the northeast would occur, it was not forecast to begin until Kelly reached 35N. It now appears the westerlies were located further south than Figure 3-15-2 indicates. Kelly



Figure 3-15-1. Kelly as an intensifying tropical storm. Kelly was accelerating to the north-northwest at this time (142259Z September DMSP visual imagery).

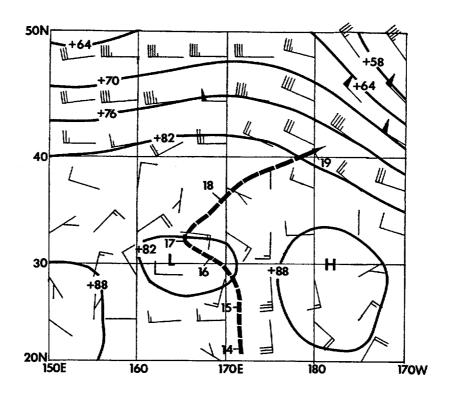


Figure 3-15-2. Mid-level tropospheric flow representative of the conditions present during the time Kelly was accelerating to the north and at the time of recurvature to the northeast. The simplified track of Typhoon Kelly is the dashed line (1600002 September 500 mb FNOC NOGAPS analysis).

weakened very rapidly after recurvature as the convection began to be sheared. By 171200Z the storm had started to loose its tropical characteristics.

In this phase, Kelly began to demonstrate intensity anomalies frequently observed in storms becoming extratropical. The low central pressures observed did not correspond well with the relatively weak winds found by aircraft reconnaissance. On

the other hand, since the central convection had nearly disappeared, the Dvorak intensity model estimated winds significantly lower than what was observed by aircraft. By 180000Z Kelly had completed its extratropical transition and the final warning was issued. The remnants of Kelly continued to the northeast and were locatable on satellite imagery until the 21st. By then the system was east of the International Dateline and moving into the Gulf of Alaska.

After Typhoon Ike moved inland over China early on 6 September, strong surface ridging from the subtropical ridge kept easterlies across much of the tropical Northwest Pacific. By mid-September, the ridging began to give way to the southwest monsoon. This helped set the stage for the development of Tropical Storm Lynn.

The disturbance that would eventually become Lynn was first noticed as an area of poorly organized convection near Guam on 19 September. During the following three days the area of convection moved west across the northern Philippine Sea with little development noted. The convection was apparently associated with a westward moving TUTT cell. As the TUTT cell weakened east of Luzon, divergence from an upper-level anticyclone north of Guam, which was ridging westward, maintained the convection. By the 22nd, a second upper-level anticyclone had developed just northeast of Luzon near the disturbance and the convection began to increase. During this entire time, surface synoptic data indicated only convergent easterly trades were present beneath the convection.

At 2300002, the convection entered the South China Sea. At the same time, a lee side low-level cyclonic circulation formed in the monsoon trough just west of Luzon, apparently the result of persistent easterly flow across the mountainous terrain of northern Luzon. This provided the low-level circulation which would accelerate the development of Tropical Storm Lynn.

During the next several hours the disturbance rapidly consolidated. Ship reports indicated the surface circulation had 10 to 20 kt (5 to 10 m/s) winds with an MSLP estimated at 1003 mb. The associated convection showed a significant increase in development as it tried to organize near the low-level circulation. In addition, a cut-off low over southern China was enhancing the outflow from the anticyclone northeast of Luzon. Based on this collective information, the Significant Tropical Weather Advisory (ABEH PGTW) was reissued at 231000Z to include this disturbance as a suspect area. The potential for significant tropical cyclone development was assissed as "fair".

During the next nine hours, the tropical disturbance continued to show signs of increased organization on satellite imagery. At 231800Z, imagery indicated that a central area of intense convection had formed. Synoptic data showed the disturbance now had winds of 20 to 30 kt (10 to 15 m/s). Based on these developments a TCFA was issued at 231900Z.

The first warning on Lynn as a tropical depression was issued at 240600Z when satellite imagery indicated that the convection was moving over the low-level circulation center and intensifying. The first few warnings forecast Lynn to slowly intensify and move to the west-northwest. This forecast track was based on guidance from the One-Way Interactive Tropical

Cyclone Model (OTCM). During the next 18 hours Lynn did intensify some, reaching tropical storm strength at 241800Z and peaking at 40 kt (21 m/s) at 250000Z. After that point in time, since Lynn had been moving slowly west-southwest away from the upper-level anticyclone northeast of Luzon, it lost its upper-level outflow and entered a shearing environment. This resulted in a displacement of the convection to the north of the low-level circulation center and the start of a weakening trend (Figure 3-16-1). In addition to the shearing, the enhancement of the anticyclonic outflow by the cut-off low over southern China had now ceased as the low dissipated at about 2500002.

At 0600Z on the 25th, it was apparent that Lynn had become a sheared system and that no further intensification would likely occur. The closest convection was located more than 120 nm (222 km) to the northeast. Lynn was now expected to follow a west-southwest track along the northern periphery of the low-level monsoon trough until it dissipated over central Vietnam. Tropical Storm Lynn posed no further forecast problems after that except for the difficulty in positioning the exposed low-level circulation center at night.

During the twenty-four hours prior to landfall, Lynn did experience a flare-up of its convection. Synoptic data at 0000Z on the 27th showed that the upper-level anticyclone had reformed near Hainan Island and that the flow over Lynn had become weak but diffluent. Also possibly contributing to this convective flare-up prior to landfall was convergence of the low-level flow and orographic lifting; both caused by the mountainous terrain inland of the Vietnam coast. After making landfall 50 nm (93 km) southeast of Da Nang (WMO 48855) Lynn turned northwest dissipating along the Vietnam/Laos border after 271800Z. There were no reports of damage or injuries from Tropical Storm Lynn.



Figure 3-16-1. Tropical Storm Lynn being sheared. The exposed low-level circulation is southwest of the main convection (2502237 September DMSP visual imagery).

During a four week period extending from the last week of September until the middle of October, a large amplitude long wave trough persisted in the western North Pacific. This trough weakened the subtropical ridge and displaced it to the east of its climatological position. As a result, tropical cyclones developing in the western North Pacific would accelerate to the north and recurve almost as soon as they developed. Tropical Storm Maury was the first of five storms to develop in the western North Pacific during this period. As would be the case with the four storms after it, Maury failed to show any significant westward movement prior to accelerating to the north and recurving.

Tropical Storm Maury formed near Marcus Island (Minami Tori-Shima (WMO 47991)) at approximately the same time that Tropical Storm Nina was developing some 700 nm (1296 km) to the west-southwest. Nina's proximity would ultimately have a significant influence on Maury's future.

Maury was originally detected early on 27 September as an area of developing convection on the northeast extension of the monsoon trough. Initially the trough was linked to the trailing end of a midlatitude front and this may have supplied some low-level vorticity which aided in the

rapid development of the system.

The disturbance was first discussed on the 270600Z Significant Tropical Weather Advisory (ABEH PCTW) as one of several weak circulations embedded in the trough. During the next 10 hours it became evident that only two circulations would dominate. Consequently the ABEH was reissued at 271600Z to indicate this concern. These two circulations would soon develop into Maury and Nina respectively.

The disturbance continued to develop at a rapid pace; much faster than JTWC anticipated. Dvorak intensity analysis performed on the 271800Z imagery indicated that 25 kt (13 m/s) winds were present. The imagery over the area two hours later showed that a well-defined compact low-level circulation center had developed. Consequently, a TCFA was issued at 272300Z. At 272341Z, Dvorak analysis of Figure 3-17-1 indicated that 35 kt (18 m/s) winds were now present in this rapidly developing system. Based on the satellite intensity analysis, JTWC issued the first warning on Maury as a 35 kt (18 m/s) tropical storm at 280000Z. Synoptic data during this period was unable to shed any light on the true intensity of Maury.

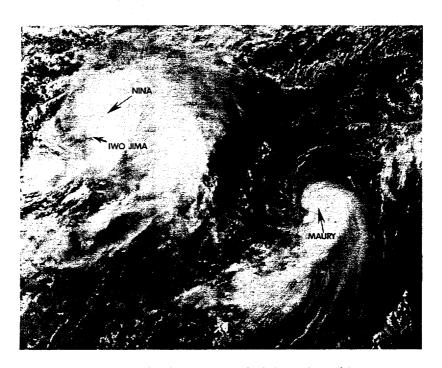


Figure 3-17-1. A compact Tropical Storm Maury just prior to issuance of the first warning. Dvorak intensity analysis of this imagery indicated that 35 kt (18 m/s) surface winds were present. This prompted JTWC to warn on this storm. The much larger Tropical Storm Nina is developing to the west (2723412 September DMSP visual imagery).

The first aircraft reconnaissance, conducted early on the 28th, quickly found the well-defined circulation center at 280303Z and reported that Maury was stronger than expected. Maximum surface winds of 50 kt (26 m/s) were found both southwest and northeast of the center. Consequently, the 280000Z warning was ammended to reflect these higher wind speeds.

During the next 30 hours, Maury moved slowly west, then northwest and further intensified reaching its peak intensity of 60 kt (31 m/s) at 290600Z. From now on the movement and intensity of Maury would be governed primarily by the much larger Tropical Storm Nina.

The upper-level anticyclone which was located just east of Nina exerted considerable pressure on Maury's convection from the start. The large anticyclone brought strong northerly upper-level winds over Maury which displaced the convection to the south. As a result, Maury's low - level circulation center was consistently located near the northwest edge of the convection (Figure 3-17-1). This strong wind shear prevented Maury from ever attaining typhoon strength.

In addition to affecting Maury's intensity, these strong winds aloft may also have been responsible for preventing Maury from turning to the north on 27 and 28

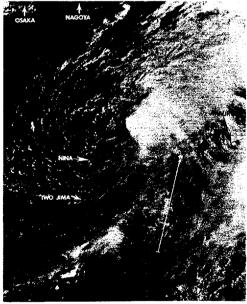


Figure 3-17-2. The exposed low-level circulation of Maury is now located just northwest of the main convection. Nina which by now had weakened to 30 kt [15 m/s], is located almost due west [3000422] September DMSP visual imagery).

September. It is likely that the outflow from the anticyclone descended and generated a weak mid-level induced ridge north of Maury which temporarily prevented any significant movement of the storm until Nina had moved further north.

On 29 September, Nina began to move northeast and approach Maury. This brought Maury under the influence of Nina's large low-level inflow. As a result, the weak ridge eroded and Maury began to accelerate to the north. As Maury accelerated to the north, the strong upper-level winds continued to displace Maury's convection away from the low-level center. This caused Maury's low-level circulation to become exposed (Figure 3-17-2) and marked the start of the weakening trend. The subtropical ridge located to the east of Maury was also a factor contributing to the acceleration. With these two factors combined, Maury reached a top speed of 26 kt (48 km/hr) between 300600Z and 301200Z.

The presence of the subtropical ridge dominated the JTWC forecast philosophy from the start. Maury was forecast to move around the ridge and recurve to the northeast. The actual movement was fairly close to the predicted track, although forecasting the speed of movement and the latitude of recurvature was difficult due to the influence of Nina.

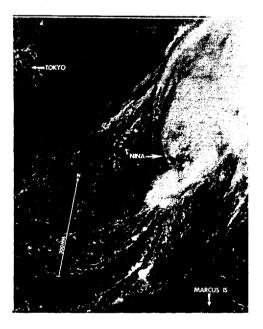


Figure 3-17-4. Imagery of Tropical Storm Nina just after the reconnaissance flight in Figure 3-17-3 was conducted. Maury is not locatable (0100227 October DMSP visual imagery).

At 301200Z, Maury was approximately 320 nm (593 km) northeast of Nina. Both storms were now moving to the northeast around the subtropical ridge. Instead of accelerating to the northeast like storms normally do, Maury slowed since it had entered Nina's larger circulation. With Nina moving to the northeast at 28 kt (52 km/hr) it took less than 12 hours to catch Maury and assimilate it into its circulation.

Maury was no longer identifiable on satellite imagery after 3018312; however, aircraft recomnaissance several hours later was still able to locate both Maury and Ninæ (Figure 3-17-3). Satellite imagery at this time however, showed that only one storm, Nina, was present (Figure 3-17-4). At 010002, with Maury's continuation as a separate system highly unlikely, the final warning was issued.

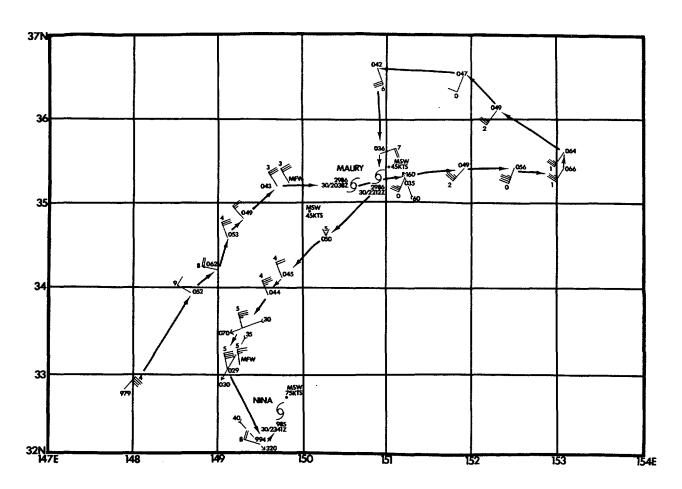


Figure 3-17-3. Although Tropical Storm Maury was no longer identifiable on satellite imagery, aircraft reconnaissance late on the 30th was still able to locate the storm's center. Wind and height data are from the 700 mb level. "MFW" represents the maximum observed flight level winds and "MSW" represents the maximum observed surface winds. The arrows with wind direction and speed represent the surface winds at that point. The number on the wind barb represents the tens digit of the 700 mb wind direction.

Tropical Storm Nina was the third tropical storm to develop in the monsoon trough during the latter half of September. Despite originating in a region favorable for cyclogenesis, Nina never intensified beyond 55 kt (28 m/s). This was due to the inability of an upper-level anticyclone to persist over the storm. The last phase of Nina's life was noteworthy due to the storm's reintensification and assimilation of Tropical Storm Maury into its circulation.

On the 25th of September, a midlatitude frontal system moved across the western North Pacific. As the front passed north of the monsoon trough, the trough was pulled to the northeast on the 26th. At 270000Z, the trough extended from the central Philippine Sea northeast to near Marcus Island (Minami Tori-Shima (WMO 47991)) where it became connected with the trailing edge of the cold front. Embedded in this trough were several weak circulations; most noticeable were the ones northeast and northwest of Guam. These would later develop into Tropical Storms Maury and Nina respectively.

Synoptic data at 270000Z indicated a closed 1004 mb circulation had formed 500 nm (926 km) north-northwest of Guam. The convection associated with the disturbance was poorly organized, but a large upperlevel anticyclone north of Guam was providing good outflow channels to the south and east.

During the following twelve hours the circulation and the associated convection moved north and consolidated. At 2712002 numerous ship reports indicated the system had intensified and was detaching from the trough. Tropical cyclone development during the next 24 hours now became a distinct possibility. Consequently, the Significant Tropical Weather Advisory (ABEH PGTW) was reissued at 271600Z upgrading the potential for development of this disturbance to "fair". This was followed by a TCFA at 272030Z based on satellite imagery which showed the disturbance was consolidating and becoming comma shaped.

The first aircraft reconnaissance flight into Nina took place late on the 27th and found only a sharp trough oriented northeast to southwest with an MSLP of 998 mb. However, a band of 30 to 40 kt (15 to 20 m/s) winds were observed south of the trough axis. This prompted the issuance of the first warning at 2800002.

During the following 24 hours, Nina moved slowly north reaching an intensity of 45 kt (23 m/s) at 2812002. Nina failed to develop a central dense overcast (CDO) as would be expected with normal tropical cyclone development. Instead, due to the displacement of the upper-level anticyclone to the east of the low-level circulation,



Figure 3-18-1. The broad exposed low-level circulation of Tropical Storm Nina (2901022 September NOAA visual imagery).

Nina more closely resembled a subtropical system. The convection was located poleward and eastward of the low-level center, and the radius of maximum winds was removed from the center. In addition, reconniassance aircraft found only sight temperature increases at the center.

This displacement of the convection north and east of the low-level center introduced uncertainty in the storm's position on the night of 28 September when the low-level circulation was poorly defined. Analysis of satellite imagery indicated that the upper-level circulation center passed east of Iwo-Jima (WMO 47981), but the surface winds at Iwo-Jima remained from the southeast until about 281800Z. This clearly indicates the surface circulation passed west of the island. During this time, synoptic data was essential in fixing the surface center since

the low-level center was not locatable on satellite imagery.

Early on the 29th, Nina entered the westerlies and the convection was displaced even further to the east remaining under the strongest upper-level diffluence. This resulted in a weakening of the storm. The broad low-level circulation was now continuously exposed, generally 100 to 180 nm (185 to 333 km) west of the main convection (Figure 3-18-1).

By early on the 30th, Nina had weakened to depression strength with reconnaissance aircraft unable to locate the low-level circulation center and satellite imagery indicating several possible low-level circulation centers. Nina was now forecast to dissipate over water during the next 12 to 24 hours. However, this weakening was to be temporary.

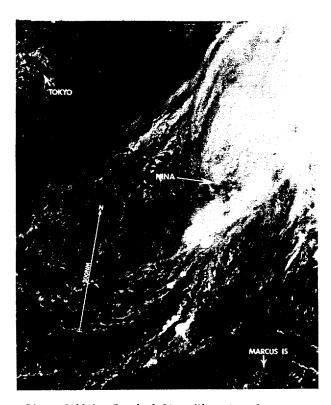


Figure 3-18-2. Tropical Storm Nina at maximum intensity. Maury is now assimilated into Nina's circulation (0100222 October DMSP visual imagery).

Between 300600Z and 301800Z, the low-level circulation moved rapidly northeast under the active convection resulting in a rapid reintensification of Nina. During this intensification, Tropical Storm Maury became incorporated into the larger circulation of Nina. However, there is no evidence to indicate that this intensification was due to the presence of Maury. At 0000Z on 1 October, Nina reached maximum

intensity of 55 kt (28 m/s) (Figure 3-18-2).

Early on the first of October, extratropical transition began. The convection rapidly decreased during the day as Nina continued to the northeast. Nina became extratropical between Oll200Z and Oll500Z, with the final warning being issued at Oll800Z.

Typhoon Ogden was the first of a series of eight tropical cyclones during the month of October which established a new record for northwest Pacific tropical cyclone activity for that month. Ogden like the two storms before it, moved almost due north from the time it developed until it began to recurve. Ogden had great difficulty in becoming vertically aligned and would probably never have attained typhoon intensity if it had not accelerated after recurvature thereby adding the translation speed of movement to the storm's wind field.

The disturbance that developed into the eighth typhoon of the season was initially detected as a weak surface circulation west of Truk (WMO 91334) on the 3rd of October. No significant convection directly associated with the circulation was evident on satellite imagery at the time. The disturbance moved to the northwest over the next 18 hours and became part of the eastward extension of the resurging southwest monsoon trough. Synoptic data at 040000Z indicated a 10 to 20 kt (5 to 10 m/s) surface circulation was present, with an MSLP near 1008 mb. The persistence of the circulation prompted its inclusion in the 040600Z Significant Tropical Weather Advisory (ABEH PGTW).

The monsoon trough began to extend northwestward on the 4th as it had a week earlier when Tropical Storms Maury and Nina developed. As the circulation became embedded in the trough, the disturbance followed the trough orientation and tracked to the northeast. Some poorly organized convection associated with the surface circulation could now be detected on satellite imagery. Upper-level flow up to this time was weak but generally diffluent.

On 5 October, the convection indicated a further improvement in organization and was now consolidating in the northeast

Figure 3-19-1. Ogden at the time the first warning was issued. Dvorak intensity analysis indicated that 25 kt (13 m/s) surface winds were present (0700022 October DMSP visual imagery).

periphery of the monsoon trough, several degrees northeast of the surface circulation. An upper-level anticyclone was also observed to be developing over the disturbance. Early on the 6th, the convection moved slightly southwest and continued to increase in size and organization. This brought the low-level circulation in closer proximity to the mid and upper-level features.

It was determined from sparse synoptic data at 060000Z that the circulation had turned more northward with an MSLP likely below 1004 mb. This led to the issuance of a TCFA at 060400Z. At 060600Z, a ship near the disturbance's center reported a 1002 mb pressure to confirm the earlier analysis.

The first of seven aircraft reconnaissance flights into Ogden occurred early on 6 October. A surface center was not located but a sharp low-level trough oriented northeast to southwest with an MSLP of 1000 mb was evident. Maximum sustained winds of 20 kt (10 m/s) were reported southeast of the trough axis. The second aircraft reconnaissance mission closed-off a circulation center at 062227Z with an MSLP of 999 mb and reported 15 kt (8 m/s) winds near the broad center. Winds of 35 kt (18 m/s) were found approximately 170 nm (315 km) east-northeast of the center associated with the tight pressure gradient between the developing Ogden and the subtropical ridge to the northeast. Intensity estimates from satellite analysis at this time indicated surface winds of 25 kt (13 m/s) were present. Although the disturbance was still located within the monsoon trough, satellite data indicated the system was moving north and separating from the trough. This in combination with the aircraft data prompted the issuance of the first warning on Ogden as a 25 kt (13 m/s) tropical depression at 070000Z (Figure 3-19-1).



Over the next 24 hours, Ogden tracked around the southwest periphery of the mid-Pacific ridge. The ridge was retreating eastward in advance of a mid-latitude trough approaching from Japan. Although the first four JTWC warnings forecast eventual recurvature to the northeast, the actual recurvature was much sharper than anticipated, with significant acceleration occurring during the first twenty-four hours of the forecast period. This was due to the mid-latitude trough moving east faster than anticipated, resulting in a more rapid retreat of the mid-Pacific ridge. This quickly put Ogden under a southwesterly steering flow.

At approximately 071600Z, Ogden obtained tropical storm intensity. At this time, Ogden was already accelerating to the northeast. Part of the storm's intensification during the next 30 hours would be a result of the forward translational speed being added to the true wind speed. This would consistently put the stronger winds in the southeast semicircle.

The only land affected by Ogden was Marcus Island (Minami Tori-Shima (WMO

47991)). Ogden passed just to the east of the island at approximately 080200Z. The island was subjected to the weaker, north-west semicircle of the storm, and as a result, no damage was reported. The highest known wind occurred at 080000Z when northeast winds of 27 kt (14 m/s) were observed. At the same time the sea-level pressure was 990.3 mb. Only two hours earlier, aircraft reconnaissance reported an MSLP in Ogden of 993 mb. This suggests that the intensifying surface center passed very close to the island.

At 1200Z on 8 October, the midlatitude westerlies began to accelerate Ogden to the northeast in earnest and Ogden began its transition to an extratropical low as it attained typhoon intensity (Figure 3-19-2). A combination of the extratropical transition and a 20 kt (37 km/hr) northeast movement contributed to an expanded asymmetric wind field and to the typhoon force winds in the southeast semicircle. Aircraft reconnaissance at 082132Z reported 70 kt (36 m/s) surface winds 30 nm (56 km) from the surface center in the southwest and southeast quadrants.

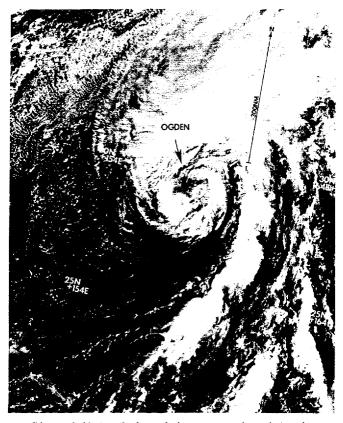


Figure 3-19-2. Typhoon Ogden near maximum intensity. Ogden was already beginning its extratropical transition at this time (0823217 October DMSP visual imagery).

The ARWO also verified that extratropical transition had commenced. Stratiform clouds were observed in the surface center and a 10 nm (19 km) northeast tilt was present from the surface to the 700 mb center. In addition, the measured MSLP was only 993 mb. This would normally support winds of 55 kt (28 m/s) according to Atkinson-Holliday (1977) pressure-wind curve. This discontinuity is often observed during extratropical transition.

The southwesterlies continued to shear Ogden as it accelerated to the northeast, further separating the 700 mb and upper-level centers from the surface center. Ogden weakened to tropical storm strength approximately twenty-four hours after it obtained typhoon strength, even though

maximum sustained winds of 77 kt (40 m/s) were indicated from satellite imagery. The satellite intensity estimates at this time were based on the Dvorak model of a subtropical system. Consequently, Ogden's 25 kt (46 km/hr) movement was directly added to the initial model intensity. It was apparent on satellite imagery at 00002 on 10 October that Ogden had lost all convection and had completed its extratropical transition. It still supported 55 kt (28 m/s) winds and had a 32 kt (59 km/hr) northeast movement. At this time, the final warning was issued. The upper-level center was located more than one degree northeast of the surface center based on satellite imagery. The remains of Ogden continued northeast towards the International Dateline as an extratropical storm.

TYPHOON PHYLLIS (20W)

Typhoon Phyllis was the first of four significant tropical cyclones to develop in the monsoon trough during a two day period. Three of these would form in WESTPAC, with the fourth, Tropical Cyclone 02B developing in the Bay of Bengal. Of the four, Phyllis was by far the strongest, reaching a maximum intensity of 80 kt (41 m/s). However, despite its strength, Phyllis caused no reported damage as it remained over water throughout its life.

As an intenisfying Typhoon Ogden began to accelerate to the northeast on 7 October, a broad area of troughing and low-level convergence persisted in its wake. By late on the 7th, the seedling of Phyllis was being analyzed as a weak surface circulation embedded in the trough east of Guam. During the next day-and-a-half, the disturbance

drifted to the northeast with no significant development noted. Figure 3-20-1 depicts the surface situation at 090000Z as Phyllis finally began to develop. A broad trough extends southwest from Typhoon Ogden across Guam and into the Philippine Sea. Embedded in this trough are two circulations; one to the northeast and one to the southwest of Guam. These would later develop into Typhoon Phyllis and Tropical Storm Roy respectively.

Although surface synoptic data was sparse near the circulation northeast of Guam, satellite imagery during the 9th and into the 10th indicated that a compact circulation was developing. This resulted in a TCFA being issued at 100630Z. At the time the TCFA was issued, Dvorak intensity analysis indicated that surface winds of 25 kts (13m/s) were present.

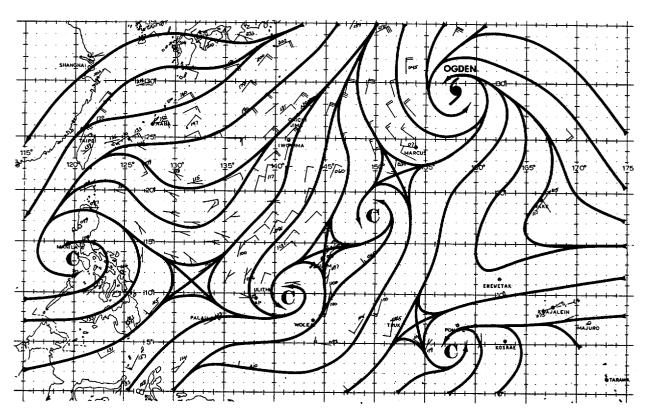


Figure 3-20-1. Surface analysis at the time Typhoon Phyllis and Tropical Storm Roy began to develop (0900002 October 1984).

The first warning on Phyllis was issued at 110000Z after satellite imagery indicated the disturbance had intensified further and now supported winds of 35 kt (18 m/s). By now Phyllis had nearly detached from the trough and would soon begin to accelerate to the north. During the next twenty-four hours Phyllis intensified rapidly reaching typhoon strength by 120000Z. The upgrade to typhoon status was based upon reports from reconnaissance aircraft and from Dvorak intensity analysis of Figure 3-20-2.

Phyllis continued to strengthen reaching a maximum intensity of 80 kt (41 m/s) twelve hours later at 121200Z. At the time Phyllis attained its peak intensity, it was located under a well-defined synoptic scale anticyclone (Figure 3-20-3). This anticyclone provided good outflow to all quadrants of the storm. As Phyllis moved north, however, the anticyclone would remain quasi-stationary

near Marcus Island (Minami Tori-Shima (WMO 47991)). As a result, less than twelve hours later Phyllis would enter the 50 to 70 kt (26 to 39 m/s) westerly flow and begin to shear and weaken.

Typhoon Phyllis maintained a predominantly northward track from the time it separated from the monsoon trough until it began to dissipate. The initial movement northward was a result of Typhoon Ogden weakening and displacing the subtropical ridge to the east. As Phyllis began to move north, a digging mid-latitude shortwave formed a vigorous cut-off low south of Honshu. This allowed the ridge east of Phyllis to rapidly build back northward, keeping Phyllis under a strong southerly steering flow. This southerly flow resulted in Phyllis accelerating to the north and prevented the typhoon from following a more typical recurvature track to the northeast.

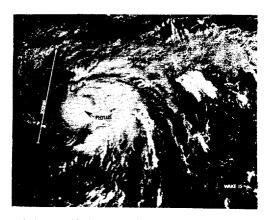


Figure 3-20-2. Phyllis at the time it was upgraded to typhoon intensity. Dvorak intensity analysis of this imagery indicated that surface winds of 65 kt (33 m/s) were present (1200022 October DMSP visual imagery).

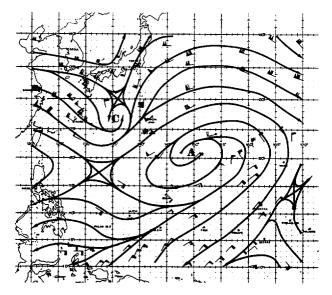
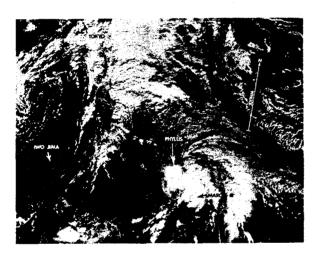


Figure 3-20-3. 200 mb analysis at the time Typhoon Phyllis attained maximum intensity. The synoptic scale anticyclone is located directly over Phyllis. The mid-level cut-off low south of Honshu extended through the 200 mb level [1212002 October 1984].

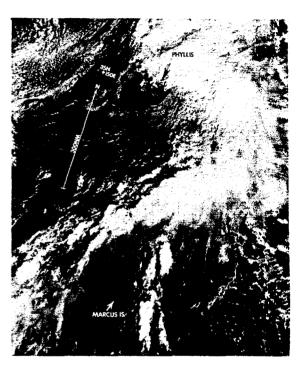
As Phyllis passed north of 25N, the cut-off low with its associated frontal system began to accelerate to the northeast. At the same time, Phyllis began to encounter the strong upper-level westerlies and the convection was displaced to the east of the low-level circulation (Figure 3-20-4). Phyllis responded by weakening at an even faster rate than it had earlier intensified.

The last aircraft reconnaissance mission was flown into Phyllis late on 13 October and found only a trough at the 700 mb level where less than twelve hours earlier, a well-developed circulation existed. At the surface, however, the

Figure 3-20-4. Typhoon Phyllis as it began to weaken under strong upper-level wind shear. Note the extratropical low with its associated frontal system to the west [1223422 October DMSP visual imagery].



aircraft still found a 999 mb surface circulation. Satellite imagery at nearly the same time showed a broad low-level circulation center defining the remnants of Phyllis (Figure 3-20-5). All the convection had been displaced to the northeast. At 140000Z, the final warning was issued as Phyllis became indistinct from the cold front transiting through the region. There were no reports of damage from Phyllis although Marcus Island (Minami Tori-Shima (WMO 47991)) did report 20 to 30 kt (10 to 15 m/s) winds for almost two days as Phyllis passed some 150 nm (278 km) to the west.



rigure 3-20-5. Phyllis as it merged with and became indistinct from a cold front. All that remained of Phyllis was a broad low-level circulation center (1323212 October DMSP visual imagery)

Tropical Storm Roy developed in the monsoon trough southwest of Guam at the same time that Typhoon Phyllis was developing further to the northeast. Despite forming in an area climatologically favorable for tropical cyclone development, Roy was unable to persist. Strong upper-level wind shear resulted in a rapid weakening and eventual dissipation of the storm after only two days in warning status.

Early on 9 October, a weak circulation was first analyzed in the monsoon trough southwest of Guam. Development of the disturbance was slow during the next twenty-four hours due to strong wind shear from the upper-level outflow of Typhoon Ogden. By early on the 10th, Ogden's influence had lessened which resulted in the convection over the disturbance increasing and becoming more organized. At 100400Z, Dvorak intensity analysis of the convective banding indicated that 25 kt (13 m/s) surface winds were present. This prompted the issuance of a TCFA at 100700Z.

During the development stage no upperlevel anticyclone was detected over the disturbance, although the flow did become diffluent. As it turned out, Roy never developed an upper-level anticyclone. This inability to develop a good outflow pattern would ultimately be responsible for Roy's quick dissipation.

The first aircraft reconnaissance mission into the system found a small 1000 mb center at 110046Z located approximately 90 nm (167 km) west-southwest of Guam. Winds of 15 kt (8 m/s) were found around most of the center except for a small area of 30 kt (15 m/s) winds in the southeast quadrant. The aircraft position of the disturbance's center confirmed what satellite imagery indicated - that the system had turned to a more northerly heading from the steady northeast course of the previous two days. This meant Roy would pass safely to the west of Guam.

Based on the data obtained by reconnaissance aircraft and the expectation for further intensification, the first warning was issued at 110227Z, valid at 110000Z (Figure 3-21-1). Later that afternoon the second reconnaissance flight found Roy had indeed intensified. The MSLP had decreased to 998 mb and minimal tropical storm force winds existed 20 to 30 nm (37 to 56 km) from the center.

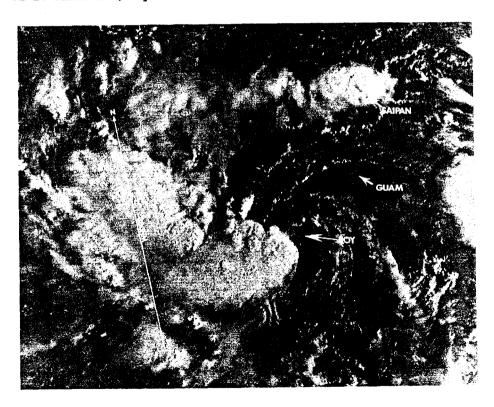


Figure 3-21-1. Roy just before the first warning was issued. The partially exposed low-level circulation center is visible on the eastern edge of the main convection. The island of Guam located 110 nm [204 km] to the northeast is completely cloud-free [1021522 October NOAA visual imagery].

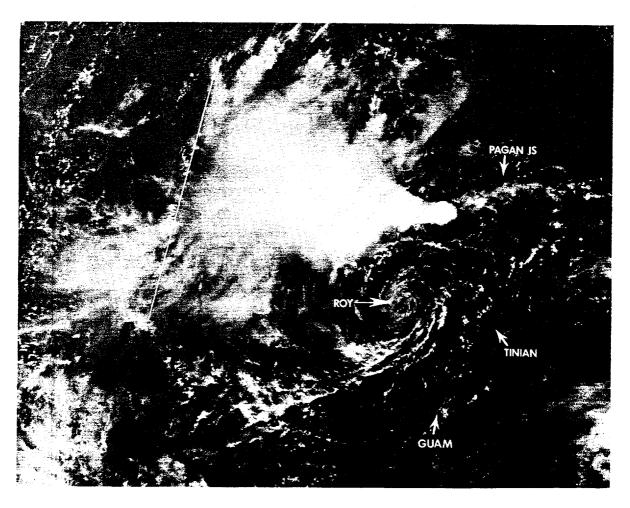


Figure 3-21-2. Tropical Storm Roy as an exposed low-level circulation center is located southeast of the convection (120002Z DMSP visual imagery).

As it turned out, these would be the strongest winds observed in Roy. Roy passed 80 nm (148 km) west of Guam as a minimal tropical storm, but caused no damage to the island. The Naval Oceanography Command Detachment (NOCD) at Brewer Field, NAS Agana, recorded maximum winds of only 14 kt (7 m/s) during Roy's passage.

As Roy moved to the north-northeast, strong easterlies from the synoptic scale anticyclone that was nearly co-located with the developing Typhoon Phyllis began to shear the storm. In addition, much of the monsoon flow which had earlier been directed into Roy was now feeding into the stronger Typhoon Phyllis. This began a weakening trend which continued until Roy's dissipation less than 36 hours later.

During the next twenty-four hours, Roy

did make several attempts to redevelop its convection about the low-level circulation center, but due to the strong shear, every attempt was doomed to fail. By the 12th, Roy had become an exposed system with the overall convection decreasing (Figure 3-21-2). However, it was at this time that the lowest MSLP was observed. At 120531Z, reconnaissance aircraft recorded an MSLP of 996 mb. Despite the lower pressures, no surface winds above 20 kt (10 m/s) were reported.

Late on the 12th, the last mission into the dissipating Roy was flown. It was unable to locate any circulation center and observed surface winds of 5 to 15 kt (3 to 8 m/s). This prompted the final warning to be issued at 130000Z as Roy dissipated over water.

Tropical Storm Susan was the third of four significant tropical cyclones to develop in the monsoon trough in less than two days. During a brief existence Susan caused considerable damage to central Vietnam despite only intensifying to 40 kt (21 m/s).

Occasionally, when a typhoon is active in the Philippine Sea a "sympathetic" storm will form in the South China Sea. Recent examples of such storm pairs are Abby/Carmen and Orchid/Percy from the 1983 season. The mechanism at work in these cases is a combination of excess vorticity and convergence at low-levels, found around circulation centers embedded in the monsoon trough, and upper-level ventilation due to the divergence in the outflow downstream (west) of the dominant typhoon in the Philippine Sea. These "sympathetic" storms often exhibit erratic movement and are the victims of significant upper-level shearing. Intensification beyond minimal typhoon strength is unusual.

As a first impression, one might

assume that this scenario was valid in the case of Tropical Storm Susan. The surface situation present as Susan was forming is shown in Figure 3-22-1. The monsoon trough extends from the Marshall Islands across Micronesia, the Philippines, Southeast Asia and into the Bay of Bengal. Embedded within this trough is the precursor of Tropical Cyclone 02B in the Bay of Bengal, the depression that is soon to be Susan in the South China Sea and the short-lived Tropical Storm Roy just west of Guam. Tropical Storm Phyllis (soon to be typhoon Phyllis) had recently separated from the trough and was accelerating to the north. The first impression, however, is incorrect in this case. Susan was not a sympathetic storm induced by either of the storms to the east, but was instead a completely independent system. The inflow patterns about Roy and Phyllis disrupt each other whereas the flow around Susan dominates the entire South China Sea and controls much more mass than the other two. Given time and more open ocean, Susan would probably have become the most intense of the four systems.

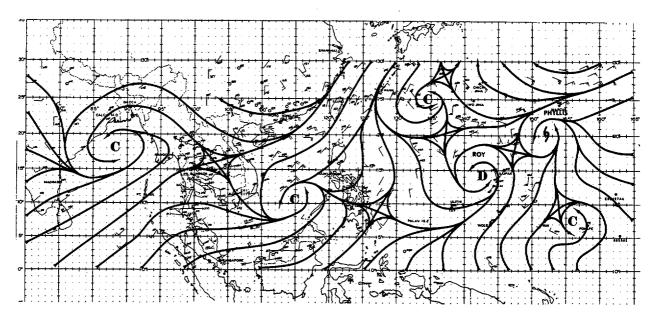


Figure 3-22-1. The 1112002 October surface/gradient level analysis during the formative stage of Tropical Storm Susan.

The upper-air pattern present during the development stage of Susan is shown in Figure 3-22-2. The anticyclone over the South China Sea is well-formed and distinct from one northeast of Guam. In fact, the upper-level anticyclone over the Pacific Ocean does not resemble the typical outflow pattern from a tropical storm. The system is much more representative of the climatological synoptic scale high. The overall pattern shows clearly that Susan developed on its own merits and not as a result of a "sympathetic" reaction.

The disturbance, which would later develop into Susan, was first noticed on 10 October as a loosely defined but very broad low-level circulation in the central South China Sea. Synoptic data showed that winds of 10 to 20 kt (5 to 10 m/s) were present

with the disturbance. The inflow pattern covered a very large area and was slow to consolidate. During this consolidation period the system remained nearly stationary.

By 110600Z the system had started to accelerate to the west along the axis of the monsoon trough. The convection and organization had both increased significantly, resulting in the issuance of a TCFA at 110730Z. By now winds near the center were 20 to 25 kt (10 to 13 m/s). The storm continued to develop as it moved quickly to the west-northwest, with the first warning issued at 111800Z. Susan made landfall as a 35 to 40 kt (18 to 21 m/s) tropical storm just north of Nha Trang, Vietnam (WMO 48877) some 16 hours later (Figure 3-22-3). After landfall, Susan turned northwest and

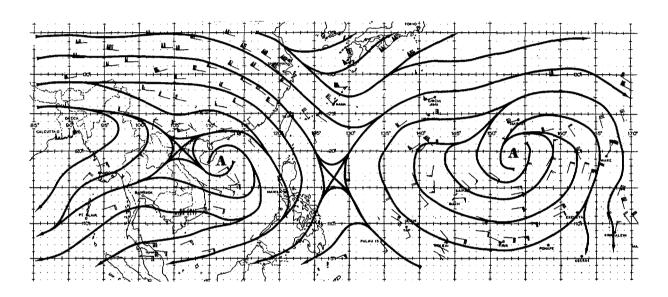


Figure 3-22-2. The 1100007 October 200 mb analysis. The upper-level anticyclone over the South China Sea is an independent system. It was not formed by the outflow pattern of the two tropical storms near Guam. (The 1112007 200 mb analysis had insufficient data to conduct a meaningful analysis).

transited up the Mekong Valley. Even though Susan dissipated as a significant tropical cyclone at 130000Z, its remnants were still evident three days later as an area of convection just to the west of Hanoi (WMO 48820). Initial reports indicate 33 people were killed and some 68,000 families left homeless due to the heavy rains and floods which accompanied Susan. Thousands of hectares of ripening autumn rice were also reported destroyed.

In summary, although Susan was simultaneously active with three other tropical cyclones, analysis proves that it was not a sympathetic storm induced by the inflow/outflow patterns of its companions. Susan started as a very broad system embedded in the monsoon trough and stayed in the axis of the through as it moved inland over Vietnam. Once over land it recurved to the north but was identifiable for several more days.

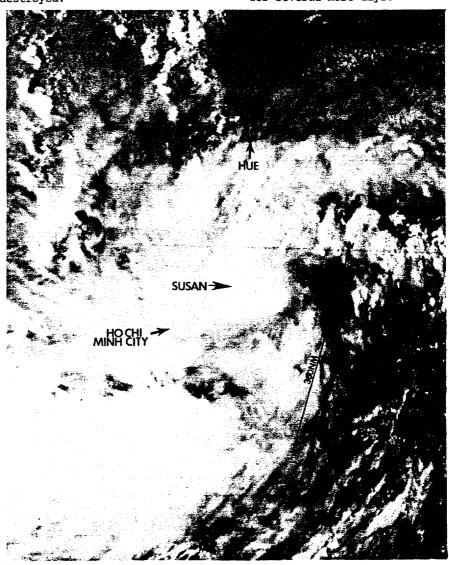
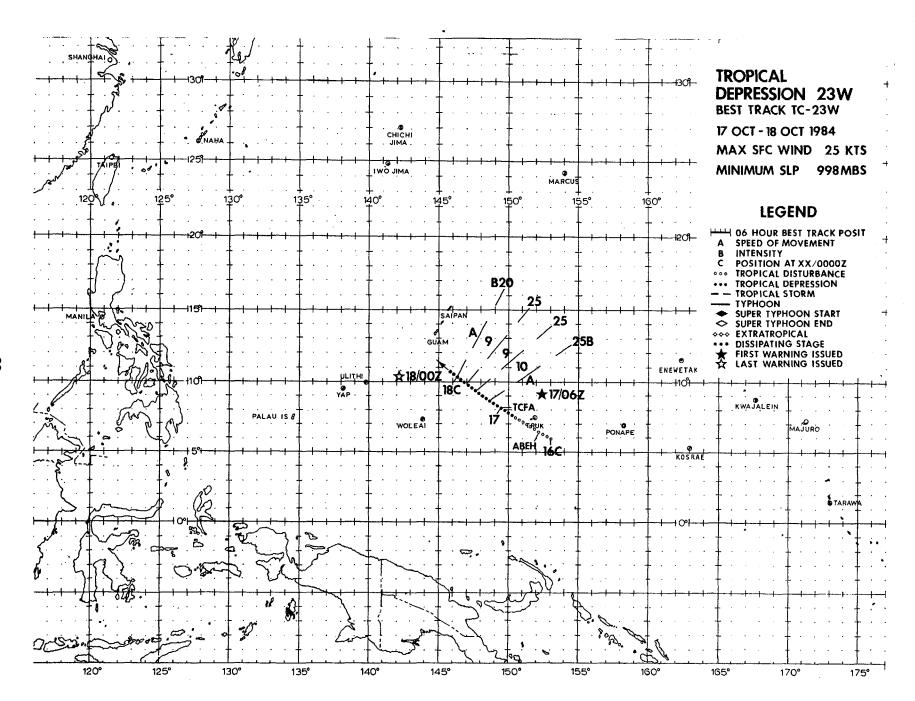


Figure 3-22-3. Tropical Storm Susan near maximum intensity. The storm made landfall over coastal Vietnam two hours later (1208222 October NOAA visual imagery).



Tropical Depression 23W was a short-lived system which developed in the monsoon trough. The lack of upper-level support resulted in dissipation only 18 hours after it became a significant tropical cyclone.

After the dissipation of Typhoon Phyllis on 14 October, the low-level monsoon trough still extended from Southeast Asia to the Marshall Islands. At 1500002, the upper-level wind-flow was similar to the pattern present several days earlier, with a large anticyclone located near Marcus Island (Minami Tori-Shima (WMO 47991)). In addition, a westward moving TUTT cell was now located near 18N 172E. At this time the convection associated with the monsoon trough showed little organization. Upper-level flow over the area was generally easterly, with northeast flow inhibiting convective development along the northern side of the low-level trough.

Early on the 16th, the convection began to show signs of increased organization. This was especially evident near the island of Truk (WMO 91334), where the eastward extension of the monsoon trough and the strongest low-level cyclonic turning were located. Synoptic data at this time indicated a 1005 mb surface circulation was present. The Significant Tropical Weather Advisory (ABEH PGTW) at 1606002 mentioned this area as having a "fair" potential for significant tropical cyclone development.

Satellite imagery during the next 18 hours showed the convection had become more organized with the development of a central convective feature. Synoptic data revealed sea-level pressures of 1003 mb to 1006 mb around the periphery of the circulation with the central pressure estimated to be near 1000 mb. These developments prompted the issuance of a TCFA at 170000Z. Upper-level data indicated the flow was now slightly diffluent as the disturbance was located in

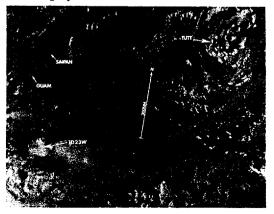
the TUTT axis.

An investigative reconnaissance flight into the disturbance closed-off a surface circulation at 170600Z and reported maximum surface winds of 25 kt (13 m/s). The MSLP had decreased to 998 mb. Since further development was expected, the first warning on Tropical Depression 23W valid at 170600Z was issued a short time later (Figure 3-23-1).

During the next 18 hours, Tropical Depression 23W moved northwest and weakened rather than intensified. Aircraft reconnaissance at 172030Z could not locate a surface circulation, but instead observed winds which indicated that a much larger circulation was developing to the southeast. Consequently, the final warning on the dissipated Tropical Depression 23W was issued at 180000Z.

Post-analysis indicates that Tropical Depression 23W dissipated as a result of unfavorable upper-level support. As the poorly organized depression moved westnorthwest along the northern periphery of the low-level monsoon trough, it moved into an area of 30 to 40 kt (15 to 21 m/s) northerly upper-level winds from the combined effects of the anticyclone (now located near Iwo Jima (WMO 47981)) and the TUTT cell to the northeast. The strong wind shear over the depression created an environment which was unfavorable for tropical cyclone development. In comparison, the area southeast of Tropical Depression 23W was located in a region of diffluent flow with the upper-level TUTT cell to the northeast enhancing the diffluence. Satellite imagery reflected this favorable upper-level outflow as much stronger convection was forming in this area. area of convection would soon develop into Typhoon Thad.

Figure 3-23-1. Tropical Depression 23W at the time the first warning was issued. A TUTT cell is located northeast of the depression {1705372 October NOAA visual imagery}.



Typhoon Thad developed southeast of Guam just as Tropical Depression 23W was dissipating several hundred miles to the northwest. Unlike its predecessor, Thad developed under favorable upper-level environment which permitted further intensification. As Thad developed, it tracked steadily to the north-northwest before recurving to the northeast. The typhoon's movement was well forecast except during the initial stages.

Late on 17 October, satellite imagery revealed that an area of strong convection was developing a few hundred miles southeast of the short-lived Tropical Depression 23W. The development of the convection was aided significantly by the presence of a weakening TUTT cell to the north-northeast which provided strong diffluence aloft over the convection.

Synoptic data at 180000Z confirmed what the last aircraft reconnaissance mission into Tropical Depression 23W had observed a few hours earlier; that a broad surface circulation was developing near Truk (WMO 91334). This circulation was underneath the developing convection and on the eastern end of the monsoon trough. Synoptic data south of the trough axis indicated the southwest monsoon was reintensifying with numerous 20 to 30 kt (10 to 15 m/s) west winds being reported.

Over the next several hours, the convection rapidly consolidated. In addition, satellite imagery and synoptic data showed an anticyclone was developing aloft providing good outflow to all quadrants. As a result, a TCFA was issued at 180630Z.

During the next 18 hours satellite imagery indicated the disturbance was moving northwest towards Guam. With Dvorak intensity analysis indicating 30 kt (15 m/s) surface winds present and 45 kt (23 m/s) surface winds forecast in 24 hours, the first warning on Thad was issued at 190000Z.

The initial warning forecast Thad to continue to move to the northwest, pass just south of Guam and gradually turn towards the west-northwest in the 48 to 72 hour period. This forecast was in good agreement with all JTWC forecast aids. Also the NOGAPS analysis and prog series indicated the subtropical ridge had returned closer to its climatological position north of Guam which further convinced JTWC that this track was reasonable.

As it turned out, this forecast would be wrong for two reasons. First, JTWC did not accurately know where the low-level center was located. Second, and more importantly, the subtropical ridge was not nearly as strong nor as far west as indicated in the analysis and prog series. Between 190000Z and 190600Z, as Thad supposedly neared Guam (WMO 91212), the winds on the island should have veered to the east or southeast. Instead, they

remained from the northeast. But analysis of satellite imagery indicated that Thad was heading directly towards Guam. Clearly something was amiss! JTWC's efforts to locate the surface center were further hampered by maintenance problems which prevented reconnaissance aircraft from penetrating the disturbances center.

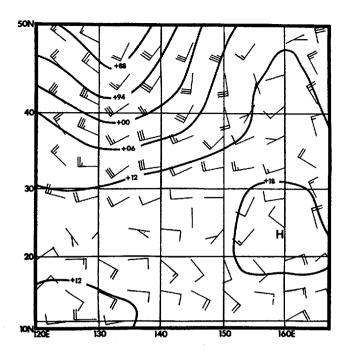
At 190728Z the first aircraft reconnaissance flight into the center of the disturbance was finally made and quickly settled the discrepency. It located Thad almost 180 nm (333 km) east of Guam with an MSLP of 990 mb. As a result, the 190600Z warning position relocated Thad some 120 nm (222 km) to the northeast! This meant that the storm would now safely clear Guam.

At 200000Z, as a now well-developed Thad continued to move to the north-northwest at 13 to 14 kt (24 to 26 km/hr), it became obvious the storm was not going to turn towards the west. Clearly the subtropical ridge was not as well-established nor as far west as the NOGAPS progs had earlier indicated (Figure 3-24-1). JTWC now forecast continued north-northwest movement for the next 24 hours with recurvature to the northeast between 210000Z and 220000Z due to the approach of a mid-latitude trough. As it turned out, this forecast track was excellent, with the speeds of movement after recurvature being only slightly faster than anticipated.

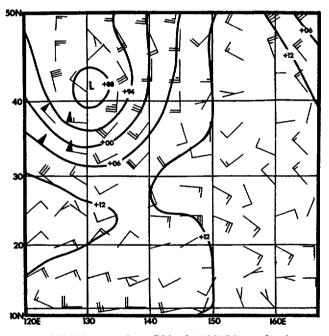
Thad intensified steadily from the time JTWC went into warning status at 190000Z, until it reached its peak intensity of 120 kt (62 m/s) at 211800Z (Figure 3-24-2). By this time Thad had begun to recurve and link-up with a mid-latitude trough. After maintaining the 120 kt (62 m/s) intensity for approximately 12 hours, Thad began a slow weakening trend which continued until the storm went extratropical. During this period, Thad accelerated from 16 to 30 kt (30 to 56 km/hr) as it became embedded in the westerlies. As would be expected with the storms that accelerate after recurvature, the strongest surface winds were consistently observed in the southeast semicircle.

As Thad accelerated to the northeast, strong upper-level westerlies began to displace the upper-level circulation and convection from the surface center. This was confirmed by the 222310Z aircraft reconnaissance fix which found the 700 mb center 28 nm (52 km) east-northeast of the surface center. All significant convection was now located north of the surface center.

On the 23rd, Thad lost most of its convection with an exposed low-level circulation center visible on satellite imagery. The final warning on this system was issued by JTWC at 240000Z. Future warnings on the extratropical low were contained in NAVOCEANCOMCEN GUAM extratropical wind warning bulletins (WWPN PGFW).



NOGAPS 700 mb 48-hour prog VT: 2012002 October



201200Z October 700 mb NOGAPS analysis

Figure 3-24-1. Comparison of the 48 hour 100 mb NOGAPS prog available to the TDO when the first warning was issued and the verifying analysis. The western extension of the subtropical ridge was forecast to extend west along 26N to near 130E. Instead, due to the effects of a digging mid-latitude trough moving into the Sea of Japan, the ridge slid east which allowed Thad to rapidly recurve to the northeast.



(a)

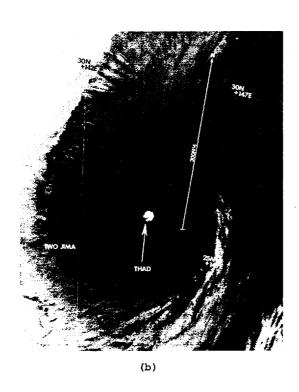
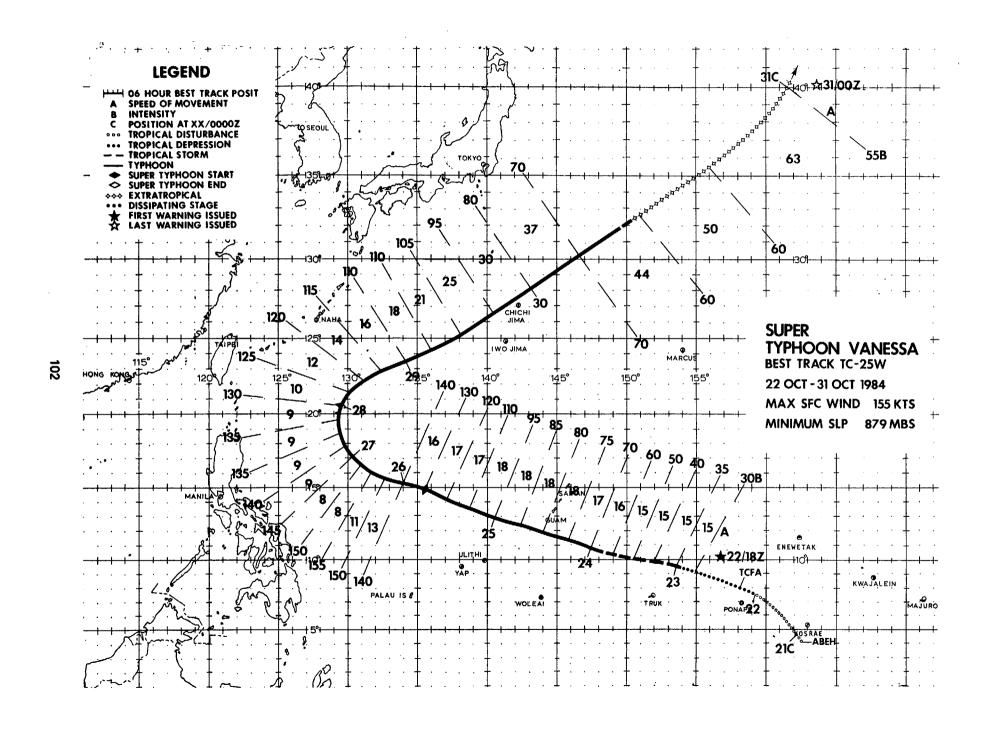




Figure 3-24-2. Three views of Typhoon Thad at maximum intensity: (a) Visual imagery (b) Infrared imagery and (c) Enhanced Infrared imagery - Dvorak Tropical Cyclone Curve. (2200022 October DMSP imagery).



Super Typhoon Vanessa, the first super typhoon of the 1984 season, also developed into the most intense storm of the year. At peak intensity Vanessa had an MSLP of 879 mb, only 9 mb above the record 870 mb observed in Super Typhoon Tip (1979). Except for a brief period when the storm brushed Guam, Vanessa remained clear of land and generally posed a threat only to shipping.

Super Typhoon Vanessa originated in the Near Equatorial Trough southeast of Ponape (WMO 91348) three days after Typhoon Thad formed some 700 nm (1296 km) further to the west. The disturbance was initially detected on 20 October as an area of convection near 4N 163E. Its rapid development resulted in the Significant Tropical Weather Advisory (ABEH PGTW) being reissued at 201900Z to include this area of convection as a suspect disturbance.

During the 21st and into the 22nd, the area of convection slowly increased in organization as the disturbance moved northwest to just north of Ponape. persistent improvement in organization during this period resulted in the issuance of a TCFA at 220500Z. Sparse synoptic data at the time of the TCFA was only able to confirm the presence of a 10 to 15 kt
(5 to 8 m/s) surface circulation. By now an
upper-level anticyclone had developed, providing good outflow to all but the northwest quadrant which was still feeling some effects from the outflow of Typhoon Thad. The first warning on Vanessa was issued at 221800Z when analysis of satellite imagery resulted in an estimate that the disturbance now supported surface winds of 35 kt (18 m/s).

From beginning to end, Vanessa followed a very climatological track becoming one of the "great-recurver" storms of 1984. From the time it attained depression strength until it began to recurve, it moved almost due west-northwest. After recurving south of Okinawa, Vanessa underwent a complex transition into an extratropical low east of Japan.

Vanessa's intensity came very close to equalling the records established by Super Typhoon Tip in 1979. Figure 3-25-1 shows the MSLP versus time for Vanessa as obtained by reconnaissance aircraft. The pressure dropped 100 mb in a 48 hour period to reach a minimum of 879 mb at 2611142. This is only 9 mb higher than the 870 mb recorded in Tip. (These pressures convert to 155 kt (80 m/s) and approximately 165 kt (85 m/s) for Vanessa and Tip, respectively, using the Atkinson and Holliday (1977) pressure-wind relationship).

The initial warning forecast Vanessa to move west-northwest and pass over Guam within 48 hours as a 65 kt (33 m/s) typhoon. The accuracy of the first forecasts gave the military and civilian communities on Guam sufficient time to properly prepare. Consequently there was little structural damage on the island and no personal injuries when Vanessa did approach as an 80 kt (41 m/s) typhoon. Vanessa's closest point of approach to Guam was 90 nm (167 km) to the south-southwest at 241100Z. Sustained winds above 30 kt (15 m/s) were recorded at numerous locations on the island with a peak gust of 59 kt (30 m/s) recorded at the Naval Oceanography Command Center (NAVOCEANCOMCEN) building on Nimitz Hill.

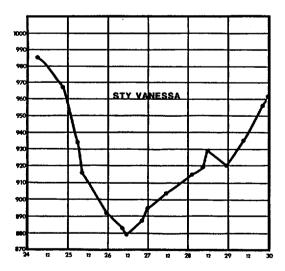


Figure 3-25-1. Time cross-section of Vanessa's minimum sea-level pressure as measured by reconnaissance aircraft. The pressure dropped 100 mb in a 48 hour period reaching a low of 879 mb at 2611142. This is only 9 mb higher than the record 870 mb observed in Super Typhoon Tip in 1979.

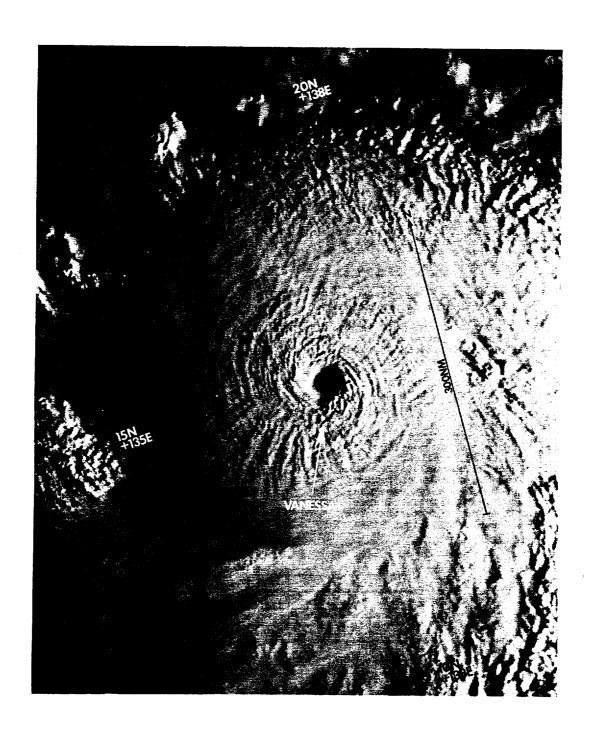


Figure 3-25-2. Super Typhoon Vanessa near maximum intensity (2522332 October NOAA visual imagery).

The only significant damage on Guam occurred to vegetation. An estimated 1.7 million dollars worth of crops were lost, principally bananas. Flooding was also reported in the southern coastal areas of the island.

Vanessa continued to intensify and move west-northwest after it passed south of Guam. The dominate synoptic feature was the subtropical ridge north of Vanessa which redeveloped in the wake of Typhoon Thad. Vanessa moved along the southern side of the ridge for nearly five days before recurving. It was just prior to recurvature, at 2612002 that a peak intensity of 155 kt (80 m/s) was attained (Figure 3-25-2). The ARWO flying the 2611142 fix mission that observed the 879 mb MSLP, described the 10 nm (19 km) circular eye as exhibiting a "fishbowl effect" with the convection in the eyewall spiralling vertically to the point of resembling corkscrews. During this flight, at a 700 mb height of 2022 m, the 700 mb temperature within the eye was an exceptionally high 30°C. Vanessa remained a super typhoon from 251800Z to 280000Z.

The recurvature which eventually took place on the 27th and 28th was initially

forecast on the 250000Z warning. A frontal system over eastern China was identified as the mechanism for recurvature. Vanessa was forecast to recurve at 21N to 22N, but actually turned to the northeast at 20N as the frontal system moved slightly faster than predicted. At no point during this period was Typhoon Warren in the South China Sea considered to be a factor in Vanessa's movement since Vanessa was the dominant storm both in size and strength.

The final phase of Vanessa's life was a complex transition to an extratropical low. Interaction with the front began shortly after recurvature. The 282330Z aircraft reconnaissance mission indicated the transition was underway with stratocumulus undercast present throughout much of the storm. Vanessa continued to weaken until the transition was complete.

Post-analysis indicates that extratropical transition was completed by 301200Z as satellite imagery showed no convection was present. Vanessa transitioned to a storm force low along the front and rapidly moved off to the northeast. The final warning was issued at 310000Z. Typhoon Warren was the most erratic moving tropical cyclone of 1984. The system was the subject of two TCFAs. It made both a cyclonic and anticyclonic loop and varied in speed from quasi-stationary for 12 hours to 8 kt (15 m/s). Warren's erratic movements were due to interactions with eastward moving mid-latitude troughs and Super Typhoon Vanessa and due to its location in the monsoon trough.

The precursor of Warren appeared late on 17 October as an area of poorly organized convection at the trailing end of a shear line approximately 300 nm (556 km) northeast of Mindanao. Synoptic data at the time indicated that a broad 15 to 25 kt (8 to 13 m/s) circulation was collocated with the convection and embedded in the monsoon trough. Over the next 24 hours the convection persisted and appeared to be separating from the shear zone while increasing slightly in organization and intensity. This prompted the first TCFA to be issued at 181500Z. Aircraft reconnaissance investigated the alert area at 190159Z and found a broad weak surface circulation with an MSLP of 1006 mb. Satellite imagery now showed the convection to be decreasing which was confirmed by the ARWO who reported that no significant convection was directly associated with the disturbance. The TCFA was cancelled at 191130Z based on the lack of persistent significant convection near the low-level center, strong upper-level easterly winds over the region, and the proximity of the disturbance to land.

Over the next several days the surface circulation weakened and moved west-southwest along the trough axis across the Philippines and entered the South China Sea on 22

October. During this period synoptic data indicated that several weak circulations were embedded in the monsoon trough. Late on 22 October the tropospheric pattern became more favorable for development. Synoptic data showed that west of Palawan a strong northeast monsoon outbreak combined with a moderate southwest monsoon to the south had produced a well-defined surface circulation. Meanwhile, upper-level diffluence developed over the South China Sea on the western edge of an anticyclone located east of Luzon (Figure 3-26-1).

On 23 October the disturbance rapidly developed. Satellite imagery at 230300Z showed that an exposed low-level circulation center was present some 30 to 60 nm (56 to 111 km) southeast of the developing intense convection. Satellite data also indicated that the tightly wrapped surface circulation was moving north towards the convection. The 30 to 40 kt (15 to 21 m/s) east-southeast upper-level wind over the disturbance, while providing some diffluence, which contributed towards development, also hindered the surface circulation from aligning with the convection. At 230600Z the disturbance was again mentioned on the ABEH, followed several hours later by the second TCFA at 231100Z. With continued development evident, the first warning was issued at 1800Z. Infrared satellite imagery at the time of the first warning indicated the surface center was now located on the eastern edge of the Central Dense Overcast (CDO). Although Dvorak satellite intensity analysis on the 231800Z infrared imagery indicated that 35 kt (18 m/s) winds were present, JTWC did not upgrade Warren from

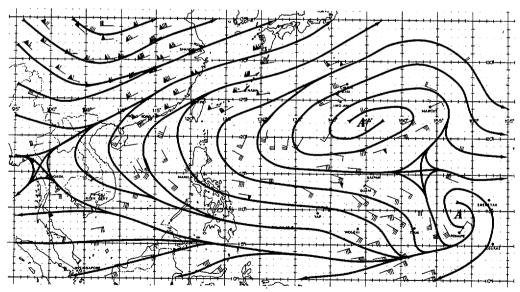


Figure 3-26-1. 200 mb analysis at 2300007 October. The diffluence over the South China Sea was sufficient to allow Warren to develop, although it would later hinder the low-level circulation from becoming collocated with the convection.

depression status until 12 hours later when visual imagery confirmed that the upgrade was warranted. Post analysis indicates this upgrade should have occurred at 231800Z. Warren and the monsoon trough moved north over the next 18 hours. Visual satellite imagery showed that a partially exposed low-level circulation center was now evident on the northeast edge of the convection.

Between 240600Z and 270000Z Warren moved erratically. It did a small cyclonic loop on the 24th and 25th, before resuming a slow westward course followed by a turn to the north and a 12-hour quasi-stationary period between 261200Z and 270000Z. This erratic movement was partially due to Warren's remaining embedded in the monsoon trough and the passage of a mid-latitude trough to the north.

During this period, despite the strong upper-level easterly winds which kept nearly all the convection west of the low-level center, Warren strengthened to typhoon intensity. Aircraft reconnaissance at 260330Z found a band of 60 to 70 kt (31 to 36 m/s) surface winds in the south semicircle of Warren. These winds were the result of the southwest monsoon enhancing Warren's circulation. Warren maintained this minimum 65 kt (33 m/s) typhoon intensity through 281800Z.

Warren became quasi-stationary at 261200Z. At this time Super Typhoon Vanessa (located some 960 nm (1778 km) to the east of Warren in the central Philippine Sea) was moving towards the northwest. Warren now came under the influence of Vanessa's large inflow and a mid-latitude trough passing to the north. (This trough would also be responsible for Vanessa's recurvature). Warren responded by turning to the east-northeast and accelerating to 7 kt (13 km/hr) (Figure 3-26-2). This placed the Philippine Islands north of 14N including Clark AB and the Subic Bay Naval Facilities in imminent danger of being hit by Warren. As a result, all Navy and Air Force Bases in the region were placed in Condition of Readiness I early on the 28th. Fortunately, Warren's interaction with Vanessa and the mid-latitude trough was short-lived sparing the Philippines a direct hit. On 28 October, with Vanessa recurving and the trough axis to the east, Warren slowed and commenced an anticyclonic turn back to the west. At its closest point of approach, Warren was 120 nm (222 km) westnorthwest of Clark AB (WMO 98327). As the effects of the trough and Vanessa eased, Warren completed its turn to the west on 29 October. The highest wind reported at Clark AB was 22 kt (11 m/s) at 282055Z, with the total rainfall on 28 and 29 October reaching 8.74 inches (222 mm). No significant damage was reported at any of the military bases.

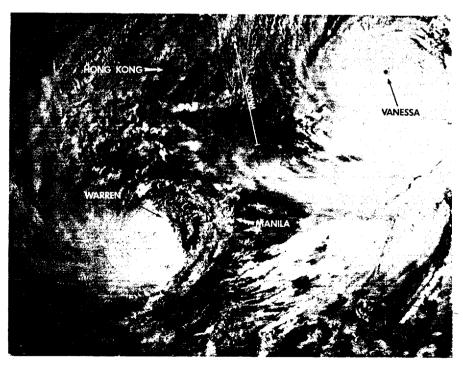


Figure 3-26-2. Typhoon Warren as it moved to the east-northeast under the influence of Super Typhoon Vanessa. Note the effects of the strong upper-level outflow from Vanessa displacing Warren's convection to the west [2723267 October NOAA visual imagery].

Other coastal areas and marine interests were not nearly as fortunate. Heavy rains caused landslides in several coastal towns killing at least 42 people. High seas capsized and sank the interisland passenger ferry, MV VENUS (746 tons) on 28 October off Torrijos and Bondoc Peninsula. About 36 people were killed but at least 213 passengers were saved. In addition, a 930 ton ship, the Lorenzo Container VIII was sunk on 28 October near 14.0N 120.6E, with eight crew members listed as missing.

Ridging developed in the low to midlevels in wake of the mid-latitude trough
passage. The subtropical ridge now became
anchored across the northern part of the
South China Sea. Another surge of the
northeast monsoon entered the South China
Sea on 29 October and began to expand
Warren's wind radii in the northern
semicircle. Aircraft data indicated that
Warren was beginning to weaken as it drew
cooler, dryer air into its center. The ARWO
reported that the center was surrounded by
stratocumulus clouds. This was also evident
on satellite imagery as the convection began
to decrease in intensity. The deep-layered
northeast monsoon flow pushed Warren's lowlevel circulation to the west-southwest on

30 October and created a significant tilt from the surface to the 700 mb center. the 31st, the hard convection was associated with the 700 mb center, displaced approximately 60 nm (111 km) west-northwest of the weakening surface center (Figure 3-26-3). JTWC issued the final warning at 310600Z since the 30 kt (15 m/s) surface center was no longer expected to become aligned with the mid-level center and the convection. This prognosis held true, but because Warren's low-level circulation was still in a region of positive low-level vorticity, dissipation occurred much slower than was forecast. Satellite imagery still showed that a well-defined low-level circulation was present 24 hours after the last warning was issued. Warren's displaced convection crossed the central Vietnam coast on 1 November with moderate to heavy rain forecast. The combination of the northeast monsoon and dissipating surface circulation just offshore resulted in 30 to 35 kt (15 to 18 m/s) winds along the Vietnam coast. By 1800Z on 1 November the surface circulation was no longer discernable on satellite imagery and synoptic data on 2 November was inconclusive as to the location of the weakening surface center. Warren had finally dissipated.

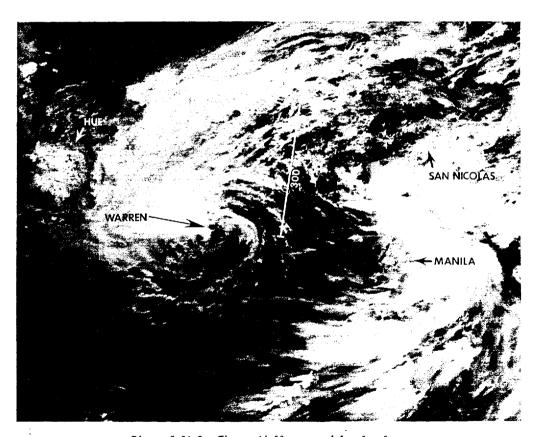


Figure 3-26-3. The partially exposed low-level circulation center displaced 60 to 70 nm (111 to 167 km) southeast of the 700 mb center. The northeast monsoon is pushing the low-level center to the southwest. This imagery was taken just four hours prior to the last warning (3102047 October DMSP visual imagery).

Typhoon Agnes was the first of three tropical cyclones to develop during the month of November. It was also the last storm of the season to directly hit the Philippines. From the time of the first warning until it made landfall over central Vietnam, Agnes moved rapidly on a nearly straight west-northwest course.

The system that eventually developed into Typhoon Agnes began as an isolated area of weak convection near the equator on 28 October. Synoptic data at the time hinted that a weak 5 kt (3 m/s) surface circulation might be present beneath the convection near lN 149E. The southwest monsoon at this time was restricted to the South China and northern Philippine Seas and did not assist in the development of this system. Even in its incipient stage, however, a small upperlevel anticyclone was analyzed over the disturbance providing good ventilation.

The system slowly developed during the next three days as the area of convection and associated weak circulation moved north-west to near 4N. Late on the 31st, satellite imagery revealed that a significant increase in convection and organization was taking place. This prompted the issuance of a TCFA at 0000Z on 1 November.

During the next six hours the disturbance rapidly pulled itself together into a potent, compact circulation. The first aircraft reconnaissance mission into the alert area at 010513Z found a closed circulation with maximum surface winds of 50 kt (26 m/s). Analysis of satellite imagery conducted just prior to the flight had indicated that only 35 kt (18 m/s) winds were to be expected. The first warning on Agnes as a tropical storm was issued a short time later at 010600Z.

From the time the disturbance was initially detected until the TCFA was issued, Agnes had moved slowly to the northwest. By early on the 1st, Agnes had moved far enough north to be influenced by the easterly flow along the south side of the broad mid- to low-level subtropical ridge which now extended from the dateline west to the coast of Vietnam. This ridge and its associated easterly steering flow persisted throughout the life of Typhoon Agnes and kept the storm on a west-northwest track from the 1st of November until it

dissipated over Vietnam six days later. This ridge was also responsible for making Agnes' wind field asymmetric. Due to the enhancement of the storm's circulation by the easterly trades, Agnes' wind field was consistently stronger and extended to a larger radii in the northern semicircle. This asymmetry would be present throughout much of the life of Agnes.

As Agnes transited the Philippine Sea it steadily intensified reaching a peak intensity of 120 kt (62 m/s) at 041800Z. This peak intensity occurred just prior to Agnes making landfall 10 nm (19 km) south of Borongan (WMO 98553) on the central Philippine Island of Samar. Figure 3-27-1 is satellite imagery of Agnes approximately twelve hours prior to reaching maximum intensity.

Agnes weakened as it crossed the central Philippines, but due to its rapid speed of movement was able to maintain typhoon intensity. After emerging in the South China Sea, Agnes once again intensified, this time to 100 kt (51 m/s). Agnes maintained this intensity until it made landfall 20 nm (37 km) north of Qui-Nhon, Vietnam (WMO 48870) at approximately 1100Z on 7 November (Figure 3-27-2). After landfall Agnes continued to track to the west-northwest and rapidly weakened. The final warning by JTWC was issued at 080000Z.

Typhoon Agnes caused substantial damage and loss of life when it crossed the Philippine Islands. Storm surge flooding of low-lying coastal areas on the islands of Samar and Leyte was particularly severe. In addition, heavy rainfall caused extensive flooding. The winds, floods and mudslides combined to leave over 350,000 homeless. At least 564 people are known dead as a result of the storm. When the number dead are combined with the number of people reported missing, the final death count is expected to be near 1000. News reports indicated that the damage exceeded 600 million pesos (30 million U.S. dollars).

When Typhoon Agnes made landfall on Vietnam three days later, there was additional destruction of property and loss of life. Heavy rains brought flooding which severely affected the rice harvest and winter crop cultivation.

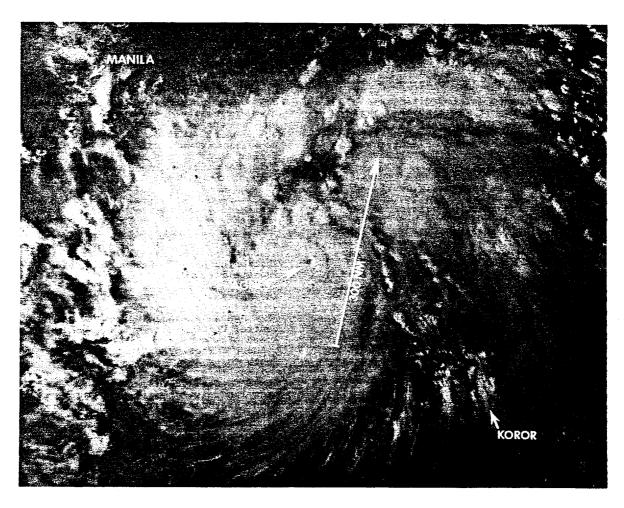


Figure 3-27-1. Agnes just prior to attaining peak intensity. At this time Agnes had a 5 nm (9 km) eye (040657Z November NOAA visual imagery).

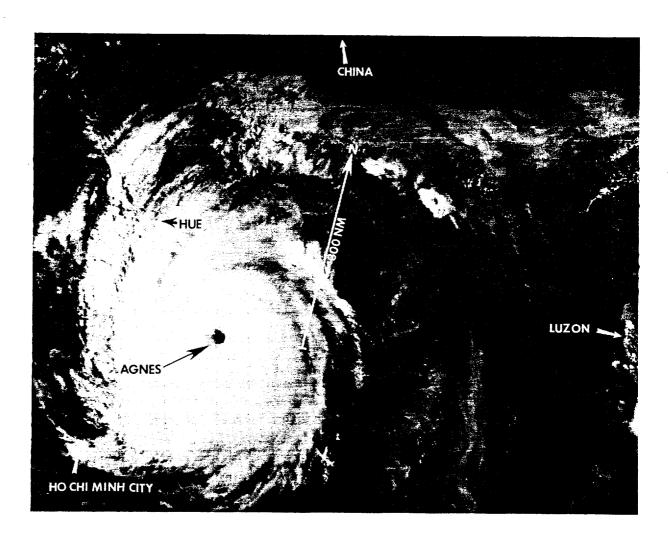
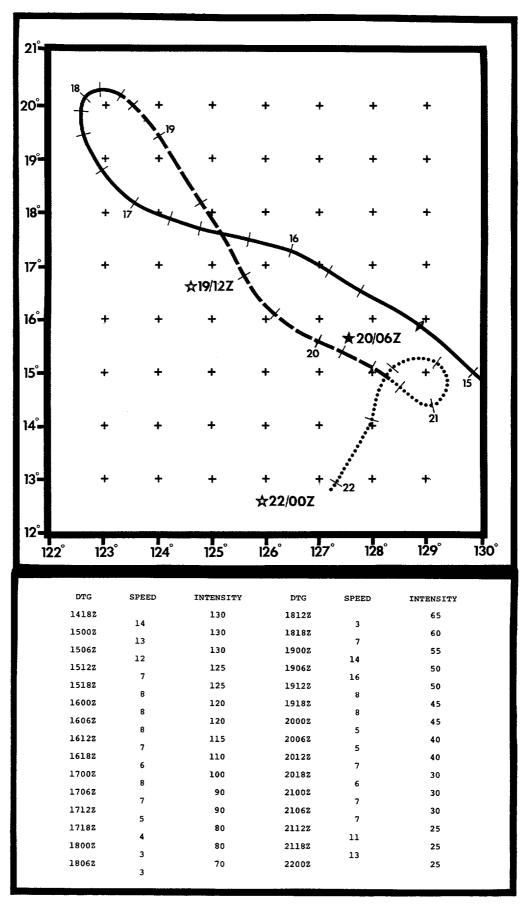


Figure 3-27-2. Typhoon Agnes at 100 kt (51 m/s) intensity just prior to making landfall over central Vietnam (070801Z November NOAA visual imagery).



The second and last super typhoon of the 1984 season led a rather unusual life. After forming east of Guam, it made a small cyclonic loop before heading to the westsouthwest. Two days later, Bill passed just to the south of Guam by which time it had accelerated to almost 20 kt (37 km/hr). After causing some damage on the island of Guam, Bill entered the Philippine Sea and turned to the west-northwest. Although it was expected to recurve to the northeast and follow a track similar to that of Super Typhoon Vanessa, due to a complex steering environment including interaction with Typhoon Clara, Bill instead turned to the southeast before eventually dissipating east of the Philippines. Although this track is unusual, it is not uncommon for late season storms to move erratically for at least a portion of their life.

Super Typhoon Bill originated as an area of convection on 7 November near 14N 154E. The convection was at the trailing end of an eastward moving cold front and this may have supplied some low-level vorticity which contributed to the rapid development of the disturbance. The rapid development of the convection resulted in a TCFA at 080200Z. At the time of the TCFA, analysis of satellite imagery already indicated that 25 kt (13 m/s) surface winds were present.

The first of a total of 35 aircraft reconnaissance flights flown against Bill found the disturbance's circulation center at 080721Z but observed surface winds of only 20 kt (10 m/s). The system showed continued development during the next 12 hours, and as a result the first warning was issued at 081800Z.

From the 8th until the 10th, Bill slowly tracked in a 25 nm (46 km) wide cyclonic loop and continued to strengthen. At 0000Z on 10 November, reconnaissance aircraft reported that Bill had intensified to a 50 kt (26 m/s) tropical storm with an MSLP of 990 mb.

Bill attained typhoon strength on the 10th. The weak steering flow which had been present was replaced by easterly flow as the subtropical ridge strengthened to the north of the storm. At approximately 100600Z Bill completed its cyclonic loop and started to move to the west and then southwest on a course that would eventually bring the typhoon to the southern tip of Guam. On the 11th and 12th, Bill accelerated and gradually intensified (Figure 3-28-1). With Bill forecast to pass within 60 nm (111 km) of Guam, tropical cyclone Condition of Readiness III was set on the afternoon of 11 November. On the morning of the 12th, with Bill now

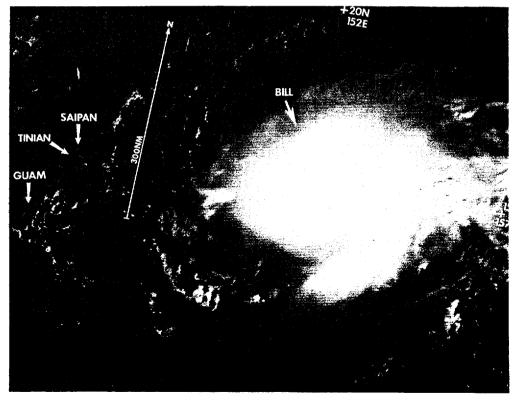


Figure 3-28-1. Bill consolidating east of Guam (1100032 November DMSP visual imagery).

forecast to pass less than 30 nm (56 km) south of the island, Condition of Readiness II was set at 112330Z.

Although Guam was forecast to be in the "dangerous" semicircle of the typhoon, the strength of the flow around the ridge did have a positive effect on Guam. Bill accelerated from 15 to 20 kt (28 to 37 km/hr) as it passed Guam thereby considerably shortening the time the typhoon affected the island. This rapid forward speed may also

have been a factor in the slow intensification of the system. Only a 15 kt (8 m/s) increase in intensity occurred during the 24 hour period between 111800Z and 121800Z as Bill approached Guam.

Condition of Readiness I was set on the evening of the 12th, as Bill neared Guam. Typhoon Bill passed the southern tip of the island at 121630Z at a distance of 12 nm (22 km). Figure 3-28-2 contains a plot of the data obtained by reconnaissance air-

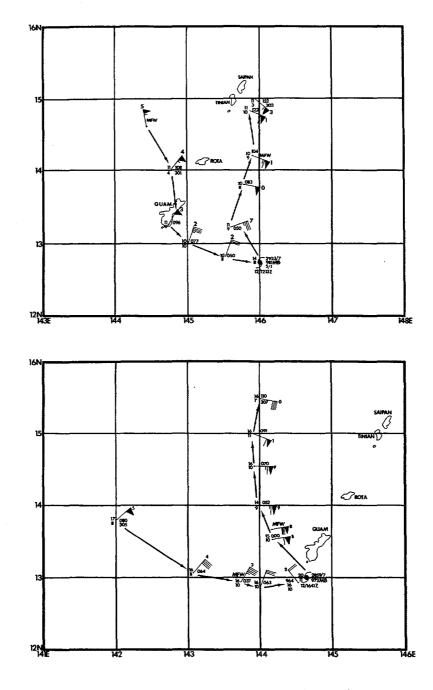


Figure 3-28-2. Plot of data obtained at the 700 mb level by aircraft reconnaissance on the two missions flown as Bill passed south of Guam.

craft during the two missions flown when Bill was at its closest point of approach to On the island itself, a maximum wind of 63 kt (32 m/s) was recorded at the National Weather Service Station (WMO 91217) at 121658Z, with a gust of 84 kt (43 m/s) recorded at Reserve Craft Beach in Apra Harbor. Typhoon Bill caused some damage on Guam, particularly to agricultural commodi-Banana trees that had been slightly damaged during the passage of Super Typhoon Vanessa were completely destroyed by Bill. Total crop damage was estimated at \$7,707,911. Some minor flooding also occurred but no personnel injuries were reported. Electrical power was out in certain sections of the island for several

Bill entered the Philippine Sea late on the 12th moving west at 20 kt (37 km/hr) and intensifying. In the 24 hour period between 131200Z and 141200Z, the MSLP dropped 54 mb to 912 mb and the wind speed increased from 95 kt (49 m/s) to 125 kt (64 m/s) (Figure 3-28-3). The pressure continued to drop for another 12 hours, with aircraft reconnaissance at 142234Z reporting an MSLP of 909 mb. This was the lowest pressure reported in Bill. Bill attained super typhoon strength at approximately 141800Z which it then maintained for 12 hours.

Bill turned to the west-northwest early on the 14th and by 141800Z had turned to the northwest. It now appeared that Bill was starting to move around the western end

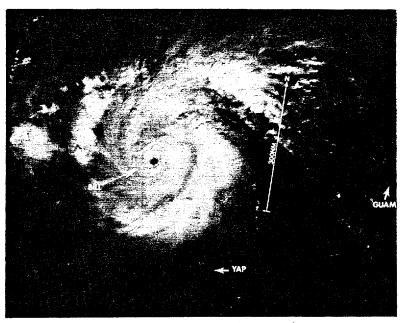


Figure 3-28-3. Typhoon Bill as it appeared on satellite imagery while undergoing rapid intensification (140044Z November DMSP visual imagery)

of the subtropical ridge. What was initially expected to be a simple recurvature scenario would soon become a complex interaction between Bill, the approaching Typhoon Clara (now developing near Truk (WMO 91334)), the mid-latitude westerlies, and the northeast monsoon. These factors would eventually cause Bill to weaken, double back on its present track and eventually dissipate.

Bill slowed down as it moved to the northwest and by 151800Z was moving at 7 kt (13 km/hr) down from the 15 kt (28 km/hr) movement of twenty-four hours earlier. This was due to the passage of a midlatitude trough to the north which weakened the subtropical ridge. Bill now began to weaken as it encountered strong upperlevel westerlies which disrupted its outflow and sheared the convection to the northeast (Figure 3-28-4). This marked the start of a weakening trend which would continue until dissipation.

At 12002 on the 15th, the subtropical ridge reintensified temporarily forcing Bill back on a west-northwest course which

it maintained until late on the 16th. On the 17th, Bill started to track to the northwest as the ridge weakened once again. It now appeared that recurvature was finally going to occur. At 1800002 Bill turned again, this time to the northeast but unfortunately this was not to be the start of the long awaited recurvature.

At this time, three factors were involved in the steering of Bill: Typhoon Clara had become the dominant circulation in the Philippine Sea (Figure 3-28-5), the flow around the subtropical ridge was waning, and the northeast monsoon was gaining strength. The subtropical ridge was the first loser in this tug-of-war as Clara's large low-level circulation started to draw a weakening Bill to the southeast. Figure 3-28-6 shows the rapidly weakening Bill with little convection remaining as it moved towards Clara.

Bill continued to track to the southeast and weaken under the combined influence of Typhoon Clara and the westerlies. Aircraft reconnaissance at 1911302 confirmed this weakening trend. The MSLP had risen to 997 mb and the maximum observed 700 mb flight

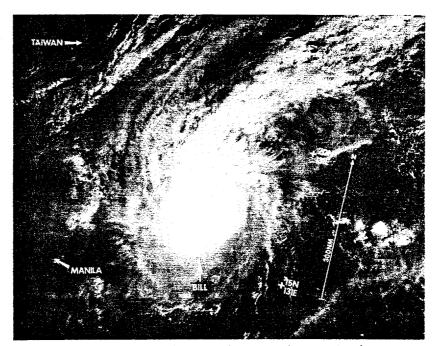


Figure 3-28-4. Bill east of Luzon as it encountered the upper-level westerlies and began to weaken. Note the cloud covered eye and the circus streaming to the northeast (1601452 November DMSP visual imagery).

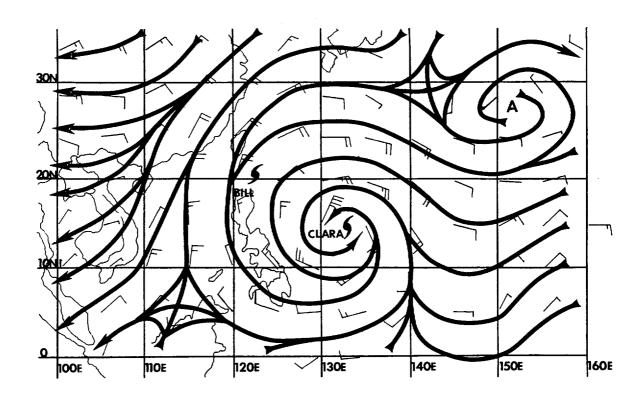


Figure 3-28-5. The 181200Z 925 mb NVA analysis showing the dominance of Typhoon Clara in the Philippine Sea. Bill which supported 65 kt [33 m/s] winds at this time was a small circulation compared to Clara and the northeast monsoon.

level wind was 28 kt (14 m/s). (Since the mission was flown at night, no surface wind data were available.) Based on the aircraft reconnaissance data and the lack of convection and organization on satellite imagery, Bill was downgraded to a tropical depression and finaled at 191200Z. As it turned out, this was premature. Early on the 20th, with Clara completing recurvature along 132E and accelerating to the northeast, its influence on Bill weakened and Bill began to regenerate some convection. Visible imagery indicated that a low-level circulation center was present. Aircraft reconnaissance a short time later, flying in the daylight at the 1500 ft (457 m) level at 2002052 reported that Bill was still moving to the southeast

and now had an MSLP of 999 mb. The aircraft also reported, that a well-defined low-level circulation with 40 to 55 kt (20 to 28 m/s) winds was present! The strongest winds were located in the western semicircle of the storm and were being enhanced by the northeast monsoon. As a result Bill was returned to warning status as a tropical storm at 2006002 (Figure 3-28-7).

Although the aircraft wind data suggests that Bill intensified between 191200Z and 200600Z, this is not considered likely. Due to the weak mid-level winds reported on the 191130Z fix mission, JTWC had the impression that Bill was rapidly dissipating. In fact Bill still possessed a well-defined surface

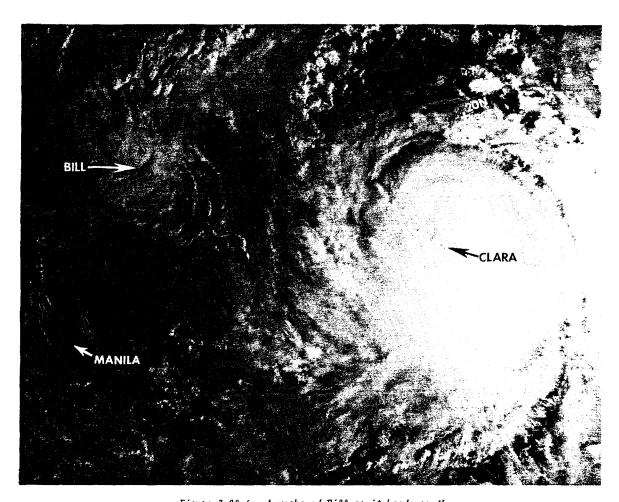


Figure 3-28-6. A weakened Bill as it heads southeast under the influence of Clara's inflow (182258Z November NOAA visual imagery).

circulation which was weakening at a much slower rate that the mid-level circulation. If the 191130Z fix mission had been able to observe surface winds it would probably have reported that 50 kt (26 m/s) surface winds were still associated with Bill.

As it turned out, the increase in convection was temporary. As Clara moved further away, its effect lessened and Bill slowed, doing a small cyclonic loop on the 21st. Bill was now under the influence of

the northeast monsoon which pushed the low-level circulation to the southwest. By the 22nd the low-level circulation became embedded in the northeast monsoon, and Bill was no longer identifiable as a significant tropical cyclone. The final warning was issued at 220000Z. Although the low-level circulation dissipated in the Philippine Sea, residual convection brought locally heavy rains to the central Philippines early on the 23rd of November.

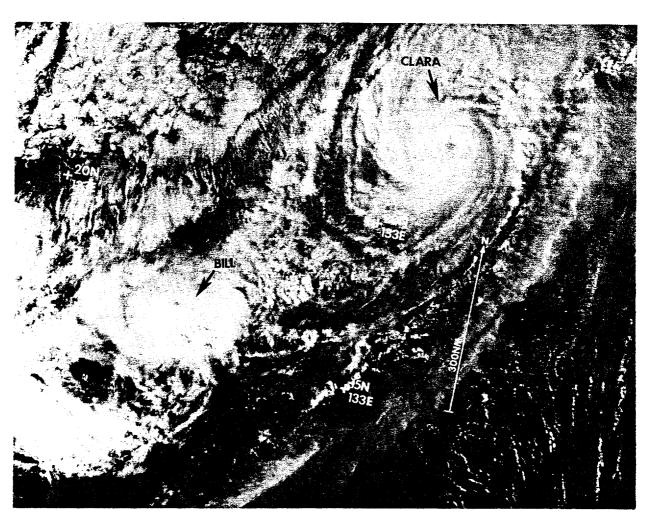


Figure 3-28-7. Typhoon Clara accelerating to the northeast and beginning extratropical transition. Bill now has more convection than 24 hours earlier, but this convective flare-up was temporary (2007002 November NOAA visual imagery).

Typhoon Clara was the last significant tropical cyclone to develop during the month of November. It developed into a textbook, late-season recurver and was noteworthy due to its effect on Super Typhoon Bill.

Clara began as a large, low-latitude disturbance in the eastern Caroline Islands. It was located by surface synoptic data before it was identified in satellite imagery. This disturbance first appeared late on 11 November as a weak circulation near 4N 164E and received first mention as a suspect area in the 120600Z Significant Tropical Weather Advisory (ABEH PGTW). By 130000Z, a very broad area of convection was associated with the circulation. The circulation's development was aided by the presence of a disturbance in the Southern Hemisphere near the Solomons which strengthened the westerly flow south of the circulation. These westerlies combined with the northeast trades to the north to supply the excess low-level vorticity needed for continued development. The upper-level

pattern was also favorable with anticyclones over Super Typhoon Bill and over the Solomons providing divergence aloft over the developing system. This cross-equatorial interaction at both the surface and 200 mb level was instrumental in the development of Typhoon Clara.

The area continued to consolidate throughout the day and at 131600Z the ABEH was reissued upgrading the system's potential for development to "fair". Analysis of satellite imagery at this time yielded an intensity estimate of 25 kt (13 m/s) with a forecast to intensify. An aircraft investigation was requested for later in the day and with continued development evident, a TCFA was issued at 132030Z. AT 140454Z aircraft reconnaissance found a surface center with 15 to 25 kt (8 to 13 m/s) winds; consequently warning number one was issued at 140600Z. Figure 3-29-1 shows Clara fifteen hours later as a 30 kt (15 m/s) tropical depression.

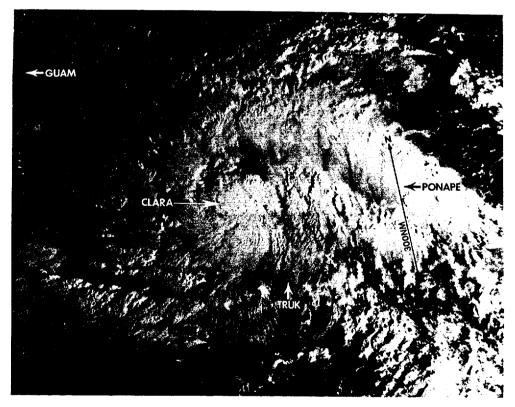


Figure 3-29-1. Clara at Tropical Depression intensity during its consolidation stage. Maximum surface winds at this time were near 30 kt [15 m/s]. This system was upgraded to Tropical Storm Clara less than nine hours later [142113Z November NOAA visual imagery].

From this point on, Clara was a well-behaved and well forecast system. As Clara intensified it developed into a large circulation. As early as 151200Z, Clara controlled as much inflow as Bill, and by late on the 16th was clearly the dominant of the two storms. Progress along its track was typical of a well-behaved fast moving typhoon, and anticipated well in advance by JTWC. Typhoon Clara recurved just east of 132E. As Clara recurved, it passed within 500 nm (926 km) of the weakening Super Typhoon Bill. This proximity to Bill disrupted Clara's outflow and resulted in a slight weakening late on the 18th and into the 19th. However, Bill's effect on Clara was considerably less than the major course and intensity changes that Clara inflicted on Bill. Late on the 19th, as Clara recurved to the northeast and opened on Bill, it

reintensified to 105 kt (54 m/s). This was just 5 kt (3m/s) less than the peak intensity of 110 kt (57 m/s) recorded prior to recurvature.

Figure 3-29-2 shows Clara after it had completed recurvature and was about to begin extratropical transition with a frontal system to the northeast. This transition was of the complex variety in which the typhoon merges with an existing front and becomes a wave on the front. This wave then propogates along the front and usually accelerates to the northeast. In this process the typhoon loses all of its convection and tropical characteristics but still retains a strong low-level wind field. In Clara's case, the transition was rapid and complete by 211200Z. The extratropical low was still discernable on satellite imagery as a frontal wave 30 hours later.

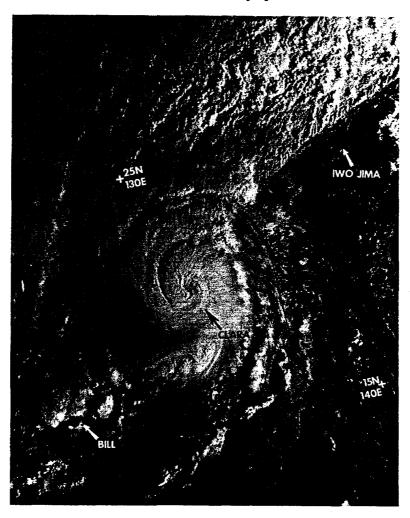


Figure 3-29-2. Typhoon Clara just after completing recurvature and about to begin extratropical transition with the frontal system to the northeast. Even this close to the weakening Super Typhoon Bill, Clara showed little indication of interaction 11922342 November NOAA visual imagery).

As Clara accelerated to the east-northeast, it passed to the north of Iwo-Jima (WMO 47981) which put the island in the dangerous semicircle of the typhoon. Sustained winds of 40 kt (21 m/s) with gusts to 63 kt (32 m/s) were reported during Clara's passage. However, no known damage was sustained on the island.

In summary, Clara was one of the classic typhoons of 1984. Forming at low-latitudes as a very broad disturbance,

Clara slowly consolidated and deepened into a 110 kt (55 m/s) system. Moving rapidly across the western Pacific, Clara recurved and, in textbook fashion, transitioned into an extratropical low while accelerating to the east-northeast. During Clara's entire lifetime, Super Typhoon Bill was active in the same portion of the ocean. Even though they were at times close to each other, Bill had no noticable effect on Clara's track and only minor influence on Clara's intensity.

Typhoon Doyle was the final tropical cyclone of the 1984 season and the only one to develop during the month of December. Doyle followed a typical recurvature track and remained over open water throughout its lifetime.

The tropical disturbance that was to become Doyle first appeared as an area of convective activity near 5N 156E at 0000Z on the 1st of December. It was mentioned as a new suspect area on the 010600Z Significant Tropical Weather Advisory (ABEH PGTW) and was given a "poor" potential for significant tropical cyclone development.

During the next 36 hours the disturbance moved west-northwest and gradually increased in intensity and organization. During this time satellite imagery showed the disturbance was developing good upperlevel support in the form of anticyclonic outflow. With the potential for significant tropical cyclone development now considered to be "fair", the ABEH was reissued at 021800Z.

Aircraft reconnaissance early on the 3rd was unable to locate a surface circulation, but did find a trough with an MSLP of 1004 mb. The system continued to show signs of increased organization prompting the issuance of a TCFA at 031100z. On the afternoon of the 4th, aircraft reconnaissance indicated that the MSLP had dropped to 1001 mb and that 25 kt (13 m/s) surface winds were now associated with the disturbance. Again no low-level circulation center could be found. Since continued slow development was evident on satellite imagery, the TCFA was reissued at 041100Z. At this time imagery showed several spiralling convective bands were present indicating that the formation of a significant tropical cyclone was imminent. Also present at this time was a Southern Hemisphere low-level circulation in the Coral Sea east of Cape York. This vortex contributed to the development of Doyle by increasing the westerly low-level flow to its south.

Satellite imagery at 0416002 indicated that the system now had some intense

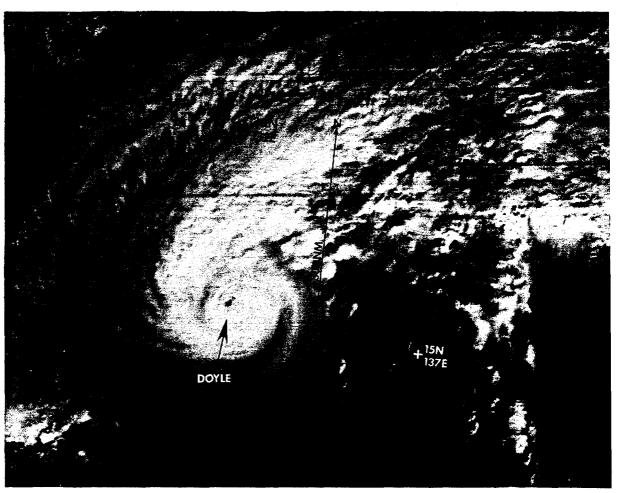


Figure 3-30-1. Typhoon Doyle one day before attaining maximum intensity (0801062 December DMSP visual imagery).

convection near the center of the developing circulation and that two intensifying convective bands were present. With Dvorak intensity analysis of this imagery indicating that 35 kt (18 m/s) surface winds were present, the initial warning on Doyle was issued at 041800Z.

An investigative flight into Doyle several hours later was finally able to locate the storm's center at 050129Z observing 40 kt (21 m/s) surface winds and measuring a central pressure of 994 mb. The surface center was very small - measuring a mere 5 nm (9 km) in diameter, with the maximum winds located 5 nm (9 km) from the center and decreasing rapidly outward. The small size of the surface center may have been a factor in the inability of previous reconnaissance flights to locate it.

During the next 48 hours, Doyle slowly intensified. Aircraft reconnaissance confirmed this slow development until the mission late on 6 December, when the central pressure was measured at 973 mb, a drop of 18 mb in just 12 hours. Maximum sustained surface winds of 90 kt (46 m/s) were observed on the north side of the storm where the easterly trades were enhancing Doyle's circulation. Doyle was upgraded to typhoon strength at 070000Z based on this information. Accompanying this intensification was a change in movement to a more northwesterly track.

The plotted values of equivalent potential temperatures versus the MSLP for the 30 hours prior to 0700002 December indicated the strong possibility of rapid deepening during the next 36 hours (Dunnavan, 1981). This indication was incorporated in the 070000Z December warning with some modification. The warnings prior to 070000Z had indicated no significant increase in intensity was likely due to the presence of the northwest monsoon flow to the north of the storm. Since that situation was still present, intensifica-tion to more than 120 kt (62 m/s) was not forecast. At this time the area north of Doyle was marked by the presence of stratocumulus clouds indicating the stability of the atmosphere in that region.

At 072047Z the MSLP had decreased to 935 mb, a fall of 43 mb in 24 hours (Figure 3-30-1). Maximum sustained winds reported by the ARWO at this time were 110 kt (57 m/s). After 0720472, Doyle's central sea-level pressure began to rise reaching 993 mb at 092037Z December (a rise of 58 mb in 48 hours). An unusual feature of Typhoon Doyle was the way the maximum surface winds lagged the occurrence of its MSLP. According to the best track intensities, which are based on all available data, Typhoon Doyle reached a maximum intensity of 125 kt (64 m/s) at 0900002 some 27 hours after the lowest minimum sea-level pressure was recorded!

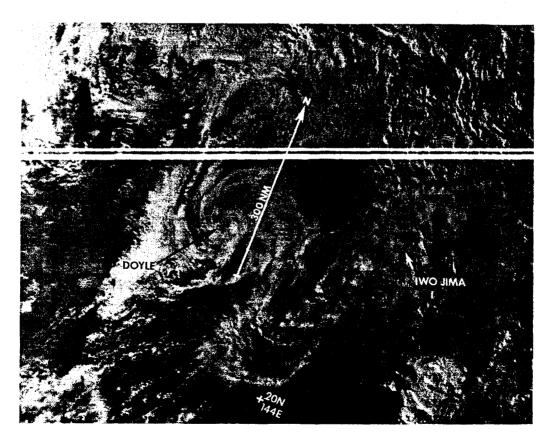


Figure 3-30-2. The exposed low-level circulation of Doyle at the time of the final warning (1106012 December NOAA visual imagery).

Between 091200Z and 100000Z, Doyle turned to the north and rapidly weakened from 95 kt (49 m/s) to 45 kt (23 m/s). Satellite imagery during this time showed a dramatic decrease in the intensity and extent of Doyle's convection. After 100000Z Doyle weakened more gradually while accelerating to the northeast. The final

warning was issued at 110600Z as the nearly convection-free low-level circulation center dissipated as a significant tropical cyclone (Figure 3-30-2).

There were no reports of damages from Typhoon Doyle as it remained over open water throughout its lifetime.

2. NORTH INDIAN OCEAN TROPICAL CYCLONES

Tropical cyclone activity in the North Indian Ocean was nearly normal during 1984. Four storms originated in this area as compared to the annual average of 4.4.

Tables 3-6 through 3-8 provide a summary of North Indian Ocean tropical cyclone activity for 1984 as compared to earlier years.

TAR	SLE 3	-6.						
1984	SIG	NIFICANT	TROPICAL CYCLONES					
TROI	PICAL	CYLONE	PERIOD OF WARNING	CALENDAR DAYS OF WARNING	NUMBER OF WARNINGS ISSUED	MAXIMUM SURFACE WIND (KT)	ESTIMATED MSLP (MB)	BEST TRACK DISTANCE TRAVELED (NM)
1.	TC	01A	26 MAY - 28 MAY	3	9	45	990	819
2.	TC	02B	12 OCT - 14 OCT	3	8	45	980	380
3.	TC	03B	11 NOV - 15 NOV	5	16	85	975	719
4.	TC	04B	28 NOV - 08 DEC	11	34	75	973	2662
			1984 TOTALS:	22	67			

TABLE 3-7.													
1984 SIGNIFICANT TROPICAL CYCLONES													
NORTH													
INDIAN OCEAN	JAN	FEB	MAR	APR	<u>MAY</u>	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1984 TROPICAL CYCLONES	0	0	0	0	1	0	0	0	0	1	2	0	4
1975-1984 AVERAGE	.1	-	_	.1	.7	. 4	_	.1	.3	1.0	1.4	.3	4.4
CASES	1	-	-	1	7	4	-	1	3	10	14	3	44
FORMATION ALERTS	FORMATION ALERTS: 4 out of 10 Formation Alerts developed into significant tropical cyclones. Tropical Cyclone Formation Alerts were issued for all significant tropical cyclones that developed during 1984.												
WARNINGS: Number of warning days:							22						
		Number of warning days with two tropical cyclones in region:						n:	0				
Number of warning days with three or more tropical cyclones in region:													

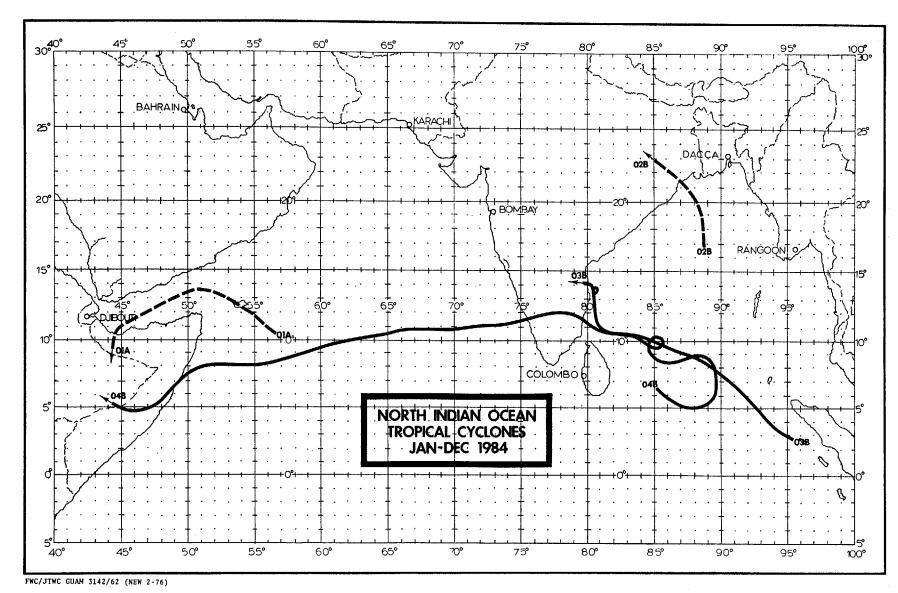
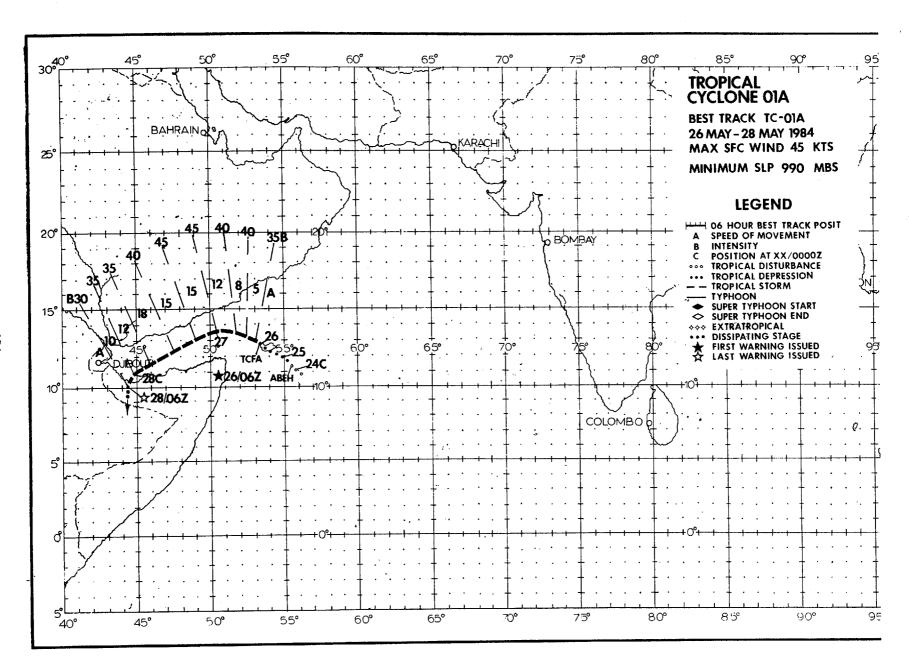


TABLE 3-8.														
	FF	EQUEN	CY OF	TROP	ICAL	CYCLO	NES B	Y MON	TH AN	ID YE	AR			
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL	
1971* 1972* 1973* 1974*	0 0	0 0 0	0 0 0	1 0 0	0 0 0	0 0 0 0	0 0 0 0	0 0 0	0 2 0 0	1 0 1 0	1 1 2 1	0 0 1 0	2 4 4 1	
1975 1976 1977 1978 1979 1980 1981 1982 1983	1 0 0 0 0 0 0 0	0 0 0 0 0 0 0	0 0 0 0 0 0 0	0 1 0 0 0 0 0 0	2 0 1 1 0 0 0 1	0 1 0 1 0 0 0 0	0 0 0 0 0 0 0	0 0 0 0 0 0 0 0	0 1 0 0 2 0 0 0 0	1 1 1 1 1 0 1 2 1	2 0 2 2 2 2 1 1 1 2	0 1 0 0 0 0 1 1 0	6 5 5 4 7 2 3 5 3	
1975-1984 AVERAGE	.1	-	-	.1	.7	. 4	-	.1	.3	1.0	1.4	. 3	4.4	
CASES	1	0	0	1	7	4	0	1	3	10	14	2	4.4	

JTWC warning responsibilty began on 4 June 1971 for the Bay of Bengal, east of 90E. As directed by USCINCPAC, JTWC issued warnings only for those tropical cyclones that developed or tracked through that portion of the Bay of Bengal. Commencing with the 1975 tropical cyclone season, JTWC's area of responsibilty was extended westward to include the western portion of the Bay of Bengal and the entire Arabian Sea.



Tropical Cyclone 01A, the only tropical cyclone to develop in the North Indian Ocean during the Spring transition season, distinguished itself by its nonclimatological track. After developing in the western Arabian Sea, Tropical Cyclone 01A turned to the west-southwest and transited through the Gulf of Aden rather than moving to the north or northwest along the climatologically favored track and making landfall along the east coast of the Arabian peninsula. This is the only tropical cyclone of record to transit through the Gulf of Aden.

The disturbance which eventually developed into Tropical Cyclone 01A was first detected on 23 May as an area of strong convection centered approximately 180 nm (333 km) southeast of Socotra (WMO 61599). The convection persisted and the disturbance was mentioned as a suspect area in the Significant Tropical Weather Advisory (ABEH PGTW) at 06002 on the 24th. The disturbance moved slowly northwestward during the next 36 hours with a gradual increase in organization. At 2600512, a TCFA was issued prompted by the persistent slow improvement in the convective organization and by indications from satellite imagery that a small but well organized low-level circulation was developing. Throughout this period, synoptic data was unable to confirm the

presence of a surface circulation. At 261055Z, the first warning on Tropical Cyclone 01A, valid at 260600Z was issued. This was based on a Dvorak intensity analysis of Figure 3-31-1 which estimated that surface winds of 35 kt (18 m/s) were present.

Tropical Cyclone OlA remained a compact system throughout its life. Even at its maximum intensity of 45 kt (23 m/s) between 0000Z and 0600Z on 27 May, the radius of greater than 30 kt (15 m/s) winds was estimated to be only 60 nm (111 km). The small size of Tropical Cyclone OlA coupled with the sparsity of synoptic data in the area precluded any verification of surface intensity estimates. Intensity estimates on this system were based entirely on Dvorak satellite analysis.

Tropical Cyclone 01A moved northwestward until late on the 26th, when it turned to the west-southwest and entered the Gulf of Aden in response to a strong subtropical ridge over Saudi Arabia. Tropical Cyclone 01A transited up the Gulf of Aden until it made landfall at 0300Z on 28 May, approximately 35 nm (65 km) west of Berbera, Somalia (WMO 63160). After making landfall, Tropical Cyclone 01A moved inland over Somalia and dissipated. There were no reports of damages or injuries from this system.

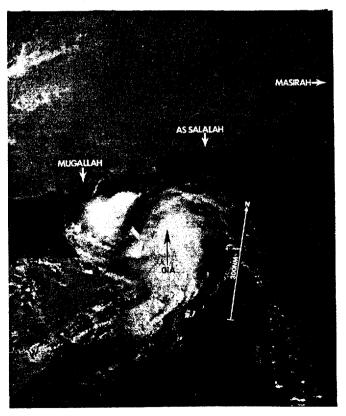
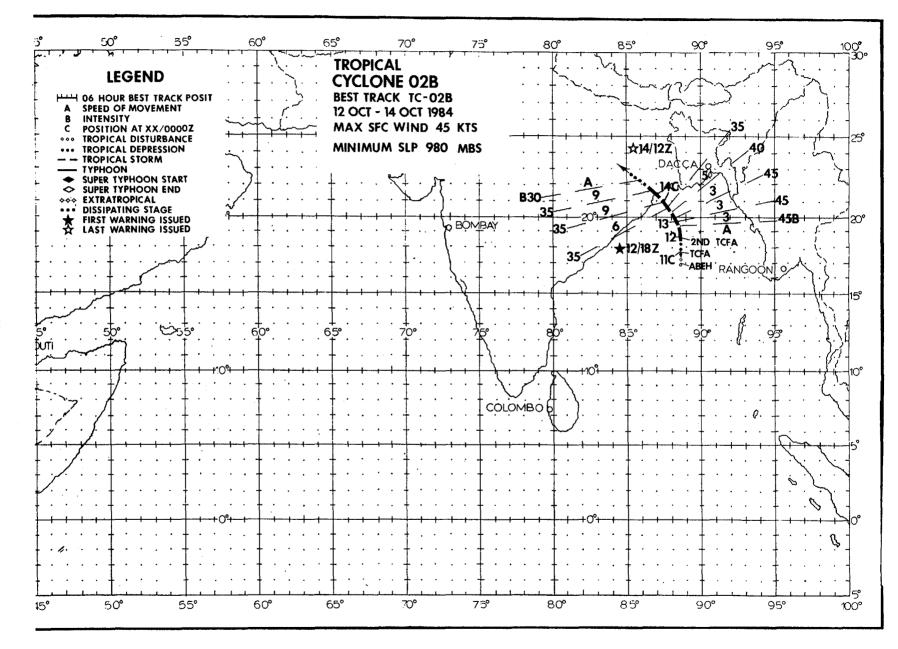


Figure 3-31-1 Tropical Cyclone 01A at the entrance to the Gulf of Aden (2606177 May DMSP visual imagery).



Tropical Cyclone 02B, the first tropical cyclone to develop in the North Indian Ocean during the Fall transition season, led a rather uneventful life. Tropical Cyclone 02B was first detected early on the 10th of October as a broad area of convection in the north-central Bay of Bengal. During the day the convection showed improved organization with cirrus plumes indicating an upper-level anticyclone existed over the disturbance. No surface synoptic data was available in the area; however, curvature of the low-level clouds indicated a developing low-level circulation was present. Dvorak intensity analysis of the 101800Z imagery estimated that surface winds of 30 kt (15 m/s) were present in the system. This prompted the issuance of the first of two TCFAs at

During the next two days the disturbance developed a broad circulation covering the head of the Bay of Bengal and intensified slowly. Upper-level support remained favorable for further intensification and the only inhibiting factor for development was the proximity of the disturbance to land which restricted the low-level inflow. Although Tropical Cyclone 02B formed in the monsoon trough, most of the flow from the southwest monsoon was being drawn into Tropical Storm Susan (22W) which was developing in the South China Sea. If Susan

had not been present, Tropical Cyclone 02B may have developed into a more potent system.

The developing cyclone tracked slowly north until 0600Z on the 12th when a turn to the northwest began. At 121800Z the first warning was issued. The initial warning on Tropical Cyclone 02B was prompted by satellite imagery which indicated that the system had intensified significantly over the past 24 hours and was now supporting winds of 45 kt (23 m/s). Once again due to lack of synoptic data, the intensity estimate was based solely on Dvorak analysis of satellite imagery. Tropical Cyclone 02B maintained this intensity for the next 12 hours until strong upper-level easterlies began to shear the convection to the west on 13 October (Figure 3-32-1). This started a weakening trend which continued until dissipation.

As it weakened, Tropical Cyclone 02B continued moving to the northwest and increased its forward speed. At about 140300Z Tropical Cyclone 02B made landfall on the coast of India approximately 10nm (19 km) south of Balasore (WMO 42895). The system weakened rapidly over land with the final warning being issued at 141200Z. Although some heavy rains accompanied this storm as it made landfall1 there have been no reports of damage.

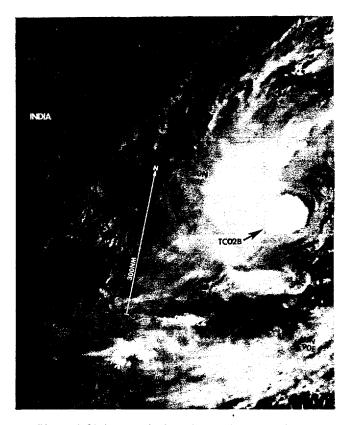
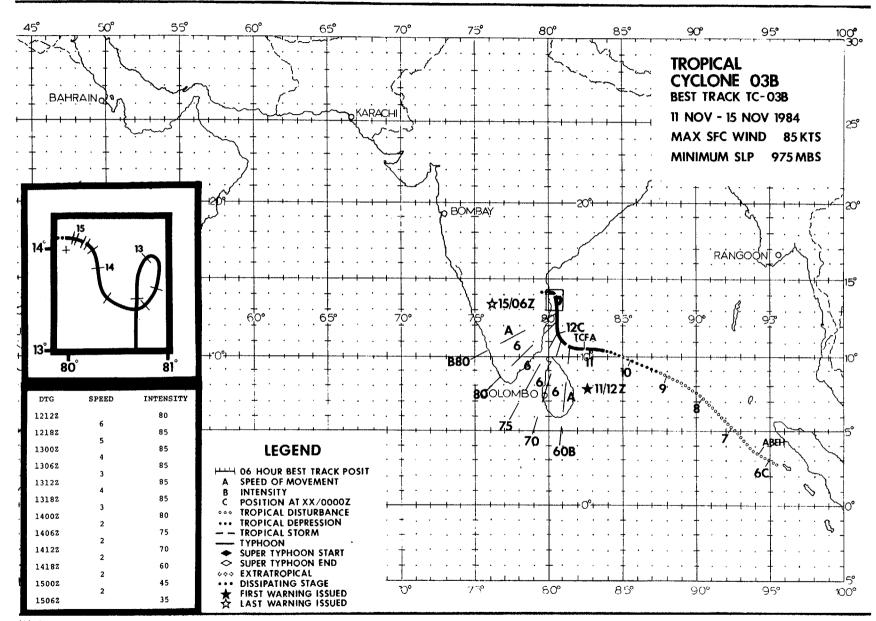


Figure 3-32-1. Tropical Cyclone 02B near maximum intensity (130446Z October DMSP visual imagery).



'62 (NEW 2-76)

Tropical Cyclone 03B, the second cyclone to form in the North Indian Ocean during the Autumn transition season, developed into the most intense of all 1984 North Indian Ocean Storms. The storm was responsible for at least 430 deaths and has been called the worst tropical cyclone to affect the central east coast of India in 15 years.

The disturbance that would eventually develop into Tropical Cyclone 03B, was first noticed late on 5 November as a broad area of poorly organized convection west of Sumatra. Over the next few days the disturbance moved northwest. Although the system showed periodic convective flare-ups, there was no permanent significant increase in organization until 9 November. By then a well-defined low-level circulation center was visible on satellite imagery. During the 9th and into the 10th, the disturbance moved to the west-northwest with only slow development noted. At that time it was thought the disturbance might make landfall over the southeast coast of India before

developing into a significant tropical cyclone. However, that was not to be the case.

Late on the 10th, analysis of satellite imagery indicated that the overall convection and organization of the disturbance was increasing. Since Dvorak intensity analysis already indicated that 30 kt (15 m/s) winds were present, a TCFA was issued at 110330Z.

Less than four hours later, JTWC received a Dvorak intensity analysis from the Air Force Global Weather Central (AFGWC) which indicated the disturbance had intensified rapidly and now supported winds of 55 kt (28 m/s)! The first warning on Tropical Cyclone 03B was issued at 111200Z.

Figure 3-33-1 is a streamline analysis of the mid-level flow that was present throughout much of the warning phase of the storm's lifetime. The dominant features are the ridging across the Bay of Bengal and the associated neutral point over the east coast of India.

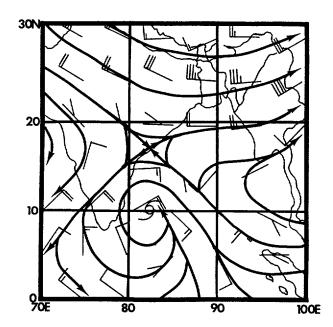


Figure 3-33-1. The mid-level flow present during much of Tropical Cyclone 03B's lifetime. Streamline analysis performed on the 1112002 November 500 mb NOGAPS wind field.

Since Tropical Cyclone 03B was firmly embedded in the southeasterly flow south of the ridge axis, the initial forecasts called for continued west-northwest movement, with dissipation over India within 36 hours. However, Tropical Cyclone 03B was to take a different course. Responding to the flow around the periphery of the ridge, the storm curved to the north and moved into the neutral point, lost all steering, and began an erratic movement. It took at least one clockwise loop (and perhaps a second) before

finally drifting slowly to the northwest towards India.

As the storm moved north on the 12th, it deepened rapidly attaining a peak intensity of 85 kt (44 m/s) at 121800Z. During this development stage, the system was vertically aligned with the upper-level anticyclone. From early on the 12th until the 14th, a 6 to 15 nm (11 to 28 km) wide eye was observed on satellite imagery (Figure 3-33-2).

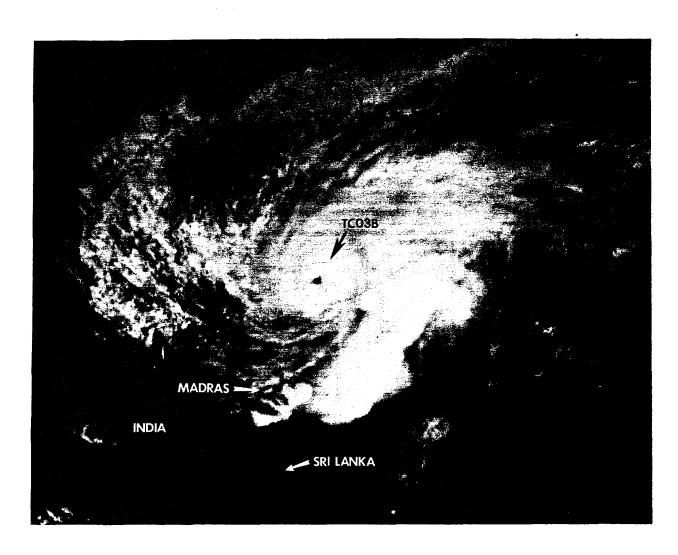


Figure 3-33-2. Tropical Cyclone 03B near maximum intensity [1304272 November DMSP visual imagery).

On 14 November, strong upper-level southwesterlies began to exert pressure on the storm. As a result, the convection began to be displaced to the northeast. Gradual weakening followed under this shearing environment until the storm made landfall where final dissipation occurred.

Unfortunately, the erratic movement and intensification of Tropical Cyclone 03B occurred very close to the east coast of

India and brought a prolonged period of heavy rain and flooding to much of the region. At least 430 are known dead as a result of the storm. Over 20,000 people were stranded in coastal villages due to flooding.

At 150600Z the last warning was issued as the nearly convection-free low-level center dissipated over land just south of Nellore (WMO 43245).

45°

50°

35°

50°

65°

70°

80°

85°

Tropical Cyclone 04B was the last tropical cyclone of 1984 to develop in the North Indian Ocean. Like two of the three storms before it, Tropical Cyclone 04B distinguished itself by its unusual track.

Early on 20 November a large area of convection extended from the southern Bay of Bengal across the equator into the South Indian Ocean. There were two weak low-level circulations associated with this convection - one on either side of the equator. Although the convection showed no organization at this time, it was extensive in size; extending from 12N to 12S and from 70E to 100E. The most intense convection was near the equator where northwest low-level flow from the northern hemisphere converged with southwest flow from the southern hemisphere.

The tropical disturbance that was to become Tropical Cyclone 04B first appeared as an organized area of convection within the broad area near 6N 85.5E. The area was mentioned on the 200600Z Significant Tropical Weather Advisory (ABEH PGTW) and was given a "poor" potential for development into a significant tropical cyclone during the next 24 hours.

The broad disturbance persisted during the next five days and by 0600Z on the 25th, the two surface circulations on either side of the equator had moved further apart and were becoming more organized. Upper-level outflow over the area appeared weak but diffluent.

By 270600Z, the disturbance in the Bay of Bengal had reached tropical depression strength and had become more organized. This was indicated on satellite imagery by convective banding and the presence of anticyclonic upper-level outflow. This system was now judged to have "fair" potential for significant tropical cyclone development during the next 24 hours. During the next 12 hours the intensity and organization of the convection continued to increase prompting the issuance of a TCFA valid at 271900Z.

At 280600Z, the system had further intensified with Dvorak intensity analysis indicating that surface winds of 35 kt (18 m/s) were present. The disturbance now had a central core of intense convection. This prompted the first warning on Tropical Cyclone 04B to be issued at 280600Z.

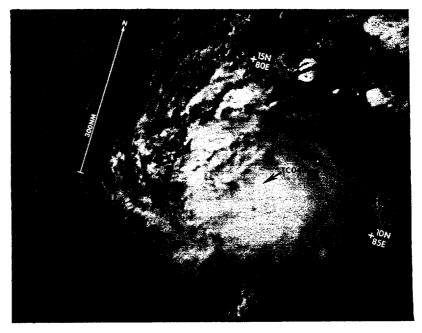


Figure 3-34-1. Tropical Cyclone 04B near maximum intensity (010509Z December DMSP visual imagery).

During the next 48 hours, Tropical Cyclone 04B moved in a slow anticyclonic loop while steadily intensifying. At 301200Z November, it had completed its loop and was estimated to have sustained surface winds of 65 kt (33 m/s). Once again this was based solely on the Dvorak intensity analysis of satellite imagery.

Tropical Cyclone 04B moved west during the next 18 hours, accelerated slightly and intensified to a peak intensity of 75 kt (39 m/s) (Figure 3-34-1). It then made a slight turn to the west-northwest and accelerated further to 16 kt (30 km/hr) as it made landfall on the east coast of India 40 nm (74 km) north of Nagappattinam (WMO 43340) at 011000Z December. After making landfall, the low-level circulation moved west across the southern tip of India and rapidly weakened. The mid-to-upper

level circulation, however, took a more northwestward track and became displaced from the low-level center by approximately 120 nm (222 km). Warning status was terminated on Tropical Cyclone 04B at 020000Z since the system had no convection associated with it and the low-level circulation was weak and poorly defined.

This weak but persistent low-level circulation now turned to the west-southwest, entered the Arabian Sea and slowly redeveloped (Figure 3-34-2). By the 3rd of December, the convection was redeveloping near the low-level center and reintensification appeared likely. This prompted the issuance of a second TCFA at 031200Z. The system continued to intensify and warning status was resumed at 031800Z December.

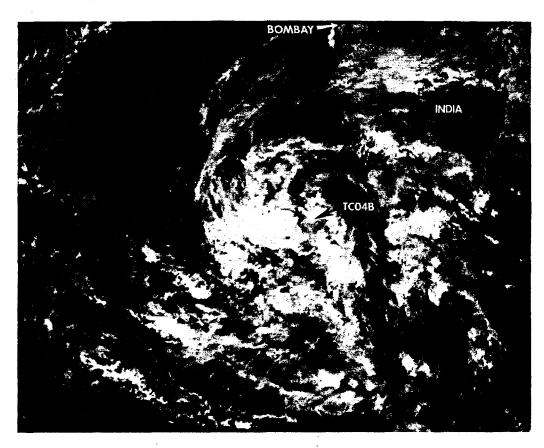


Figure 3-34-2. The poorly organized remnants of Tropical Cyclone 04B as it entered the Arabian Sea and began to reintensify (0204482 Pecember DMSP visual imagery).

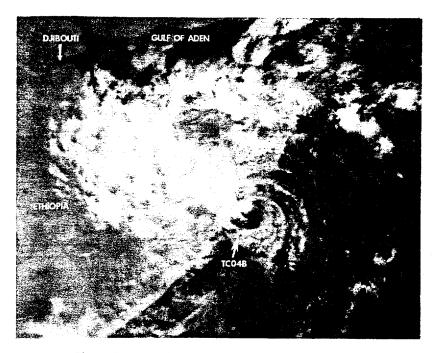


Figure 3-34-3. The exposed low-level circulation of Tropical Cyclone 04B located just off the east coast of Somalia (0706302 December DMSP visual imagery).

Tropical Cyclone 04B continued to move west-southwest, reaching an intensity of 60 kt (31 m/s) at 050600Z. For the next 42 hours it moved in a general westerly direction across the Arabian Sea around the southern periphery of a low to mid-level anticyclone located near the Persian Gulf. There was no significant change in intensity during this period.

At 070600Z, Tropical Cyclone 04B was within 25 nm (46 km) of the Somalia coast and had weakened to 35 kt (18 m/s) (Figure 3-34-3). At this point, the low-level circulation, became exposed, moved inland, and then moved southwestward along the coast for 24 hours before dissipating over land. The mid-to-upper level circulation and associated convection moved off to the northwest. The final warning was issued at 080000Z.

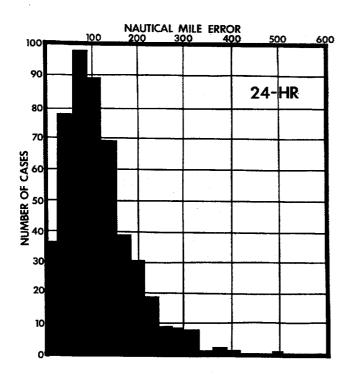


Figure 4-2

Frequency distribution of the 24-, 48-, and 72-hour forecast errors in 30 nm increments for all significant tropical cyclones in the western North Pacific during the 1984 season.

FORECAST ERRORS (nm)

	24-HR	48-HR	72-HR
MEAN:	117	233	363
MEDIAN:	101	211	316
STANDARD DEVIATION:	77	135	221
CASES:	492	378	286

